

## Authors response to comments of the Referee #3

**We thank the Anonymous Referee #3 for the interesting and important comments on our manuscript. All the individual comments are addressed below in red.**

The manuscript presents the online coupled model Enviro-HIRLAM, which is well known in the atmospheric modelers community. The manuscript is well structured and provides a comprehensive presentation of Enviro-HIRLAM development with a description of the different approaches and physical schemes implemented during the model evolution. The computational schemes and parameterizations adopted by the models are properly introduced and referenced. A minor shortcoming of this approach is that it is somewhere not very clear to the reader which computational scheme is the one chosen for the present version of the model or what alternatives are provided to the user.

### **Response:**

The revised version provides more information about computational schemes chosen for the present version of the model.

The LMCSL with monotonic filter is the scheme chosen for the present version. As of now one may be in doubt if this just an option.

A relevant number of applications are referenced for almost all the model development fields. Some of the items (e.g. pollen) are described providing explicit summary of the overall results that make the paper more readable and useful for a reader that is not willing to read the large number of referenced papers and documents. Other examples of application are mainly discussed through references and do not allow the reader to appreciate the model effectiveness and the improvement offered by the online modelling approach.

### **Response:**

We agree with the reviewer: the pollen part was not described in previous publications, so we did it in more details. Other aspects, considered in specific previous papers, are only briefly described here with corresponding references.

If the general approach of online coupling is physically sound and it can be agreed that it will probably become the prevailing modelling approach in the next future, the manuscript does not clarify, through its application examples, to what extent the online coupling and the main parameterizations introduced (e.g. urbanization) provide an improvement of model capability to predict observed pollutant concentrations and key meteorological parameters. An improvement of the analysis of the online coupling effectiveness is desirable and would make the manuscript more complete, interesting and valuable.

### **Response:**

These issues are really very important, but the previous EuMetChem paper (Baklanov et al., 2014) considered them more comprehensive and not only for the Enviro-HIRLAM model.

Text and figures include a large number of acronyms for project names, parameterization schemes, etc. Even if many of them are known, it is quite difficult for the reader to know and remind all their meaning. It would be helpful to add an acronym legend section.

**Response:** Thanks. Done.

Specific comments:

Section 1. Methodology

Lines 72-75 The authors say that Enviro-HIRLAM is being used for different research project, but most cited project have already concluded their activity. In the Figure 1 lowest box most project mentioned as ongoing are finished since a few years.

**Response:**

Many previous and recent projects are mentioned in the text (FUMAPEX, MEGAPOLI, MACC, PEGASOS, MarcoPolo, EuMetChem, CarboNord, CRAICC-PEEX, CRUCIAL, ...).

We have adjusted the info in the Figure 1 lowest box correspondingly.

Section 2.1 Modelling system structure

Line 92 The URL <http://hirlam.org/trac/wiki/> is password protected and therefore not accessible to the reader. It should be substituted with an open access web site.

**Response:**

This is the policy of the HIRLAM consortium. We are in contact with the HIRLAM web-master to open this link or to provide another open one.

Section 2.3 Atmospheric chemistry

It is not clear if the “tropospheric sulfur cycle” is a simple scheme alternative to the CBM-Z, that is presently maintained for simplified simulations (what is the specific interest?), or if it is an obsolete option which is going to be abandoned. It is not specified how the CBM-Z gas-phase chemistry scheme is interfaced with the M7 aerosol module.

Due to the relevance of secondary particle production modelling, more details would be appreciable to provide a comprehensive model description.

**Response:**

The tropospheric sulfur cycle chemistry is used together with M7 aerosol microphysics module because of its relative simplicity and low computational cost. The CBM-Z gas-phase chemistry is not interfaced with the M7 aerosol module because of several reasons: 1) the aerosol microphysics module does not include Secondary Organic Aerosols, therefore, there is no need of complex gas-phase mechanism with Volatile Organic Compounds related reactions and 2) it is too computationally expensive to use CBM-Z together with M7 for both weather and atmospheric composition prediction.

Lines 171-172 The authors say they “use KPP tools to create the gas-phase chemical mechanisms including the solvers for three chemical mechanisms.” What are the three mentioned chemical mechanisms? Only two of them have been previously presented: a) Tropospheric Sulfur Cycle, b) Gas-phase chemistry (CBM-Z).

**Response:**

Indeed, during the validation stages of creating the gas-phase schemes we used the Kinetic Preprocessor (KPP) (Sandu et al., 2006); we used KPP to create the Fortran code of three gas-phase schemes CBM-Z (Zaveri et al. 1999), GEOS-CHEM (Evans et al. 2003) and the Regional Atmospheric Chemistry Model “RACM” (Stockwell et al., 1997).

For the chemical weather prediction propose, GEOS-CHEM and RACM are very computational expensive schemes. GEOS-CHEM and RACM schemes include a large number of chemical reactions. For more simplicity we cooperate with Dr. Rahul Zaveri (Personal communication with Dr. Ashraf Zakey) in order to simplify CBM-Z and online coupled it with the Enviro-HIRLAM Model.

“Tropospheric Sulfur Cycle scheme” is a very simple sulphur scheme (Easter et al., 2004). It was ported from HAM without use of the KPP tool. Reference: Easter, R. C., S. J. Ghan, Y. Zhang, R. D. Saylor, E. G. Chapman, N. S. Laulainen, H. Abdul-Razzak, L. R. Leung, X. Bian, and R. A. Zaveri

(2004), MIRAGE: Model description and evaluation of aerosols and trace gases, J. Geophys. Res.,109, D20210,doi:10.1029/2004JD004571”

Lines 172-173 The authors say that Rosenbrock solver is usually selected. Why?

**Response:**

The Rosenbrock solver is mostly used within the air quality models communities because it is computational fast.

Line 190 What is “NWP-Chem-Liquid”?

**Response:** The “NWP-Chem-Liquid” is a thermodynamic equilibrium model, described in Korsholm et al. (2008). Many gas-phase species are water soluble and sulphate and ammonia together with water take part in binary/ternary nucleation. In order to consider these processes, a simplified liquid-phase equilibrium mechanism with the most basic equilibria is included in NWP-Chem-Liquid. This equilibrium module is solved using the analytical equilibrium iteration method (Jacobson, 1999).

Section 2.4. Aerosol formation, dynamics and deposition

Line 197 Is CAC still available in Enviro-HIRLAM or it is mentioned only for historical development reasons?

**Response:**

No, it is not used in the last reference version and in the described simulations, but can be called for specific studies. See e.g. Gross and Baklanov (2004), Korsholm (2009).

Lines 205-206 Is the aerosol type identity maintained through the model simulation and provided as separated output contribution to the total PM?

**Response:** Different aerosol types mentioned in the model description and simulations (as described in section 2.4) are provided as separate species in the model outputs along with lumped PM<sub>10</sub> and PM<sub>2.5</sub>.

Section 2.5. Emission modules and pre-processor

Line 254 Does wildfires emission module consider PM only or gas phase pollutants too?

**Response:**

The wildfires emissions were from the Finish Meteorological Institute - Fire Assimilation System v.1.1, which provides total lumped emissions. The total was split according to Andreae and Merlet, 2001 in organic and black carbon, and gaseous emissions of SO<sub>2</sub> only. The gas-phase pollutants like Nitrogen Oxide (NO) and Volatile Organic Compounds (VOCs) were not considered or processed.

Line 274 What are “transported modes”?

**Response:**

The “transported” mineral size mode in the GADS/OPAC data set (Köpke et al. 1997) is usual aerosol size mode that comes in addition to the more standard “nucleation”, “accumulation” and “coarse” mineral size modes. Köpke et al. (1997) uses the “transported” size mode to describe aerosols that have been transported over a long distance, for instance Saharan aerosols that have been blown to the Atlantic ocean.

Section 2.7. Urban parameterizations and models urbanization

This section is relevant because it highlights the need for a mass conserving transport scheme in on-line coupled NWP and ACT models. For offline coupling this request is less strict because mass consistency is usually guaranteed by the coupler module.

Line 311 Bracket missing.

**Response:** Thanks. Done.

Line 312 Grid nesting is an effective technique to increase model resolution but it is rather confusing to consider it a method to represent urban areas.

**Response:**

The nesting technics and downscaling methods are actively and successfully used for urban areas to reach the necessary resolution for resolving or parameterisation of urban features and effects. The details of this approach was described e.g. in Baklanov and Nuterman (2010).

With respect to metropolitan areas, the downscaling for finer/ better resolution allows to reproduce smaller scale meteorological patterns, and then these patterns are further modified through running the urban modules such as BEP, SM2U, BEM, etc. only for grid cells where the cities are presented.

The text of this section is modified correspondingly.

Line 315 The “calculation of the urban mixing height based on prognostic approaches” is neither described nor commented in the following text.

**Response:**

Thanks. This issue was published previously in BLM papers Zilitinkevich et al. (2002) and Zilitinkevich and Baklanov (2002). Some clarifications were done: additional text and references on specific papers are included.

References:

Zilitinkevich, S. and A. Baklanov, 2002: Calculation of the height of stable boundary layers in practical applications. *Boundary-Layer Meteorology*, 105(3), pp. 389-409.

Zilitinkevich, S., A. Baklanov, J. Rost, A.-S. Smedman, V. Lykosov & P. Calanca, 2002: Diagnostic and prognostic equations for the depth of the stably stratified Ekman boundary layer. *Quarterly Journal of the Royal Meteorological Society*, 128, pp. 25-46.

Section 2.8. Transport schemes

Line 371 Is hat symbol missing on “modified weight” in equation 6 ?

**Response:** Thanks. Yes, it is. There should be a hat over the W. Corrected in the revised version.

Line 377 “”is are” should be corrected

**Response:** Thanks. Done.

Lines 388-390 This sentence concerning Enviro-HIRLAM mass consistency for tracer transport should be better explained and discussed. What are the possible limitations caused by this lack of mass conservation? What is TR4?

**Response:** Thanks. It is a mistyping. TR4 should be Eq. (4).

We have already answered this question to Reviewer 1.

We have added a sentence to clarify that mass-wind inconsistency is a minor problem. The traditional HIRLAM is (at least in principle) wind-mass consistent. In Enviro-HIRLAM where all moisture fields are transported with the LMCSL scheme there is no formal consistency, yet, since precipitation is very similar to that in HIRLAM (except for individual convective systems that are chaotic/unpredictable in their nature), the mass-wind inconsistency is small in practice.

A more careful discussion on the issue of mass-wind inconsistency in atmospheric models would require a rather extensive addition. In principle no monotonic transport schemes can be mass-wind consistent since the monotonic limiters formally destroy the consistency.

We also add a reference to the paper: Jöckel, P., von Kuhlmann, R., Lawrence, M. G., Steil, B., Brenninkmeijer, C. A. M., Crutzen, P. J., Rasch, P. J., and Eaton, B.: On a fundamental problem in

implementing flux-form advection schemes for tracer transport in 3-dimensional general circulation and chemistry transport models, Q. J. R. Meteorol. Soc., 127, 1035–1052, 2001.

Section 3 Modelling system applications

What are the mentioned “EnvCLIMA, Enviro-HIRHAM”?

**Response:** Thanks. It is clarified/modified in the revised version.

Lines 415-418 Do the mentioned temperature changes due to indirect effects improve model results? How relevant is the improvement? The reference given by the authors is to a Project report that can be hardly available, not to a journal publication. In the following sentence (lines 420-421) the authors mention a marginal improvement on surface temperature. They also mention a redistribution effect on NO<sub>2</sub> concentration, but they do not specify if this effect improves model results.

**Response:**

Yes, these study results were described only in reports and proceeding papers. Corresponding journal paper is under preparation. The improvements due to the indirect effects exist (as shown e.g. in Fig 9), but the existing parameterisations of indirect effects need further improvement and evaluation.

Several publications of different authors (e.g. Vogel et al., 2015) also stressed that these indirect mechanisms are the most uncertain and need further improvements.

We have answered in more details on the similar question to the Reviewer 1.

Lines 442-444 and Figure 9 The authors say “the ENV run bias for precipitation with respect to its frequency and amount has been decreased compared to the REF model run (Fig. 9).” Legends printed on the pictures seem opposite to what indicated in the caption (Enviro-HIRLAM on the left). Results showed in Figure 9 seem different during different parts of simulation: until July 21st the right side simulation seems better, while the left side one seems better during the last part of the simulation. What is the difference of the overall biases?

**Response:**

It is an unfortunate mistake; the left and the right figures must be swapped.

According to observations at WMO station 6670 at Zurich, Switzerland, the mean 12 hours accumulated precipitation in July 2010 was 0.97 mm, the median was 0 mm and the precipitation variance at the site was 7.52. As for the reference HIRLAM run, the modeled monthly mean, the median and the variance of 12 hours accumulated precipitation are equal to 1.83 mm, 0.14 mm and 16.90, respectively. The Enviro-HIRLAM model with aerosol-cloud interactions predicted the mean value of 1.16 mm, the median of 0 mm and the variance of 9.53 of 12 hours accumulated precipitation for the same month. That means the reference model tends to overpredict both the precipitation frequency and its amount, but the aerosol-cloud feedbacks in the Enviro-HIRLAM model reduce such over-prediction tendencies. Moreover, the values of Fractional Bias of Ref-HIRLAM (-0.61) and Enviro-HIRLAM (-0.18) along with Normal Mean Square Error values of Ref-HIRLAM (4.17) and Enviro-HIRLAM (3.45) show improvement of the Enviro-HIRLAM prediction score comparing to Ref-HIRLAM.

Lines 480-489 A grid size of 2.5 km seems quite crude to resolve Bilbao city. In x and y directions the city seems to be described by 2 to 4 grid cells which can be hardly considered sufficient to develop a “urban signal”. Why has not been used a finer resolution? Is it due to the hydrostatic model limitations?

**Response:**

Yes, the hydrostatic approximation of the model was a limitation to increase the resolution to perform the urban simulations. However, sensitivity tests demonstrated that the 2.5 km was the optimal resolution allowing at the same time to obtain satisfactory reproducibility of the large scale processes

and to explore the urban effects at local scale without being diminished due to a coarse resolution, for a medium size city (even possibly can be considered for a small size city). For other metropolitan areas such as Paris, Rotterdam, St. Petersburg, Shanghai - a similar resolution was chosen, although for Copenhagen (with a flat terrain) the highest possible/ suitable resolution tested was 1.5 km and provided reasonable verification results. Within a selected metropolitan area there could be only a few grid cells having 100% representation of the urban fraction, but taking into account all urban grid cells, the boundaries of the cities (number of cells) could be substantially larger. Moreover, it should be noted that most of existing developed parameterizations in the physics core of any existing NWP model might be also needed to be revised when resolutions of 1 km and finer are used.

Figure 10 Why different land use classifications have been used for the two considered cities? What is the P01 modelling domain mentioned in the caption?

**Response:**

Depending on a country-by-country basis and national architectural specifics, different metropolitan areas could have different types of urban fabric with specific aerodynamical and morphological characteristics of urban districts. The size of the Bilbao metropolitan area is at least 10 times less than the Paris metropolitan area. Therefore, to harmonize the urban classification we considered that Bilbao had a Residential high and low density districts (RLD, RHD, respectively); while Paris metropolitan areas was characterised by a residential district (RD) and the city centre (CC). Also, note that for the land-use classification of the Bilbao metropolitan area, a local land-use database was used and for Paris, the land-use database CORINE 2000 was applied. (Gonzalez-Aparicio et al. 2010). The P01 domain is just one of names for the modelling domains created for the Enviro-HIRLAM model runs with the focus on the Paris metropolitan area located in the centre of the domain. It has been removed from the caption.

Line 498 Does 10% improvement refer to the correlation value?

**Response:** Yes, it is referred to the overall correlation values.

Lines 499-500 It is not clear how the mentioned correlations have been computed. Time correlation for separated hours? How many stations have been used to compute the mentioned correlations?

**Response:**

The correlations were computed for the winter and summer months, simulated averaged over each hour of the day (e.g. considering the diurnal cycle), at each of the three types of locations considered (urban, suburban and rural – Figure 11a).

Lines 501-504 Where the mentioned results for Bilbao better than those obtained without urbanization? Was the improvement significant?

**Response:**

The results have been mentioned in Gonzalez-Aparicio et al. (2013). The results of those simulations were significant since we showed that the Enviro-HIRLAM model (urbanized version) was able to simulate the effect of the Urban Heat Island over a medium size city located in a coastal and complex terrain area characterized by land-sea breeze.

Lines 512-535 The authors show that model urbanization allows to describe UHI phenomenology in Paris and Bilbao, but they do not discuss if the urbanization improves results and reduces possible model bias with respect to urban observations.

**Response:**

Gonzalez-Aparicio et al. (2013) discussed the urban parameterization implementation in the Enviro-HIRLAM model and the improvement with respect to the control simulations for the Bilbao city. The

urban effect and the results were compared with the results obtained in an experimental campaign over the city.

Lines 635-639 The mentioned effects of aerosol feedbacks on chemical composition are quite interesting. Did the mentioned changes on NO<sub>2</sub> and O<sub>3</sub> improve model results and increase its capability to reproduce measured values?

**Response:**

Unfortunately it was just a sensitivity study and a proper long-term validation was not realised yet. So, we prefer to avoid conclusions.

Figure 15 Right side color scale legend needs correction. How are correlations for separated hours computed?

**Response:**

We do not know how to change the legend scale, because the referee did not specify any required correction.

In order to compute correlation coefficients on diurnal cycle, the Enviro-HIRLAM model output was collected for separate time slices (00, 03, 06, ... 21 UTC) and observation sites, and then the correlation coefficients were computed separately for each time-slice and site.

Lines 675-677 The authors mention new model applications without providing any detail about recent results potentially relevant and interesting for the readers. The mentioned feedback mechanisms evaluation is one of the key point of the paper.

**Response:**

Unfortunately we cannot answer on all the questions of online chemistry-meteorology modelling in one this paper. Some potential applications are just briefly mentioned in the paper and they are topics for further studies and analysis. In particular the results of the CarboNord project for Black Carbon feedbacks for the Arctic are now under analyses and will be published in a separate paper.

Section 4 Conclusions

Lines 692-702 These sentences contain repetitions of the same concepts that could be removed.

**Response:** Thanks. Done.