Towards interoperable atmospheric (air flow) models in Spatial Data Infrastructures using OGC Web Services – state of the art and research questions

W. J. Eder, A. Zipf

Research Group Cartography, University of Bonn, Department of Geography

Meckenheimer Allee 172, D-53115 Bonn

<eder,zipf>@geographie.uni-bonn.de

Abstract

Interoperability in today's Spatial Data Infrastructures (SDI) is advancing itself, outspreading more and more, to the different application domains of geo-informatics. Thus having standardized web services following OGC standards, a seamless integration is feasible for a wide base of requirements. In case of planning the integration of atmospheric models into SDI, a basic approach will be developed and presented in Concept of Service Architecture. Ahead of this chapter, this review offers the state of the art in firstly OGC Web Services (OWS) and secondly by atmospheric models. Requirements opposed on the models, in the range of urban-ecology studies, are identified. The major section of the Architectural Concept deals with data preparation, OWS composition development and finally the conceptional schema of proposed model integration into SDI by OGC Web Services. As argued after, GI-standards are as well essential and reasonable for atmospheric models.

In conclusion the realization of this task by combining an atmospheric model, making use of detailed 3D city models for urban-ecological studies in Spatial Data Infrastructures will be a very interesting challenge in the near future.

1. INTRODUCTION

Environmental modeling is a very common methodology in geo-sciences (Baklanov 2000, Bruse 2007 and Seaman 2000) which is widening itself to more fields of work. This is not only induced by the results of better sensors (higher spatial-, temporal-, radiometric resolutions) but also by the increasing available computing power (processing power, storage capacity). By having the need of integrating geodata from various sources as required for meteorological observations (Schlatter 2000), it is essential to take into concern the need for standardized geodata, interfaces and web services. For example *The Open GIS Guide* states: "Data sharing makes sense for the simple reason that there is only one Earth, and we share it" (OGC 2006). Revealing the driving force, for the decision of achieving our goal, is on the one hand provide a proof of concept for integration of atmospheric models into an OGC based SDI-infrastructure. On the other side, we want to resolve further scientific question how to draw additional benefits of high-resolution city models. In this respect a better urban climate management will be possible, in order to get more precise information about local air flow conditions. This can be in the domain of air-quality for residents of densely populated cities, who will be e.g. able to get a prediction of atmospheric pollution for their spare time. So they are able to avoid areas having high air pollution. Potential user groups will be for example urban ecologists, firefighters and finally the end user having access to a 3D city model including an air flow simulation. Specialists will additionally be able to model present or future states of the atmosphere in combination by adding or replacing existing items like buildings in the 3D model. Leading to consider not only the visibility of the city structures, but although the control of air streams. Like elimina-

tion of unwanted air flow as caused by channelizing alleys. Besides this, there are further use cases in air-pollution e.g. immission reduction, or in the field of disaster simulation like the diffusion of a toxic gas from a leaking plant (Walenciak et al. 2009). The research topics with respect to atmospheric models, numerical weather models or even climate change models are very widespread. So in a first instance we focus on wind flow models in the range of micro- to meso-scales which are relevant for research in urban ecology (Jacobson 2005). From a technical point of view, similar principles could be used for other atmospheric models on the meso- or macro-scale, too, though.
The developed scheme in 3.2 is taking into concern, that the practical implementation into a *Spatial Data Infrastructure* will have to follow open geospatial standards defined by *Open Geospatial Consortium* (OGC). This shall ensure that the model will be interoperable within the range of services available in SDIs. Several SDIs on regional, national and international level are under development. A driving force behind that is in particular the EU directive INSPIRE (Infrastructure for Spatial Information in Europe). It is targeting on legislating general clauses for creating a uniform *Spatial Data Infrastructure* in the European Union creating a common environmental policy and other political provisions (GDI-DE). Leading to an open cooperative infrastructure for accessing and distributing information products and services online (Campagna 2006). Also other activities within OGC aim for a better access and interchange of atmospheric meteorological- and climatological data in a “timely and useful fashion” (OGC-METEO 2009).
The state-of-the-art is presented in chapter 2 presenting standardized geo-data and web services plus together with their interface standards, which are necessary in this context. Furthermore the considered *OGC Web Services* will be described in chapter 2.1. In second step an introduction into the different basic concepts of atmospheric models will be given. Next are the requirements imposed on the model selection. The following paragraph presents a choice of different atmosphere simulation models. This is needed in order to define their common characteristics, with respect to needed input data and parameters. This yields later on in a common or very general interface definition for them. A final discussion concludes this chapter.
The architecture for realizing web-based interoperable atmospheric modeling in SDIs includes a set of standardized *OGC Web Services*. This can be such as information storage for vector- (WFS) and raster (WCS) services. For dynamic (real time) sensor information the suite of services from the OGC Sensor Web working group (OGC-SENSOR 2009), such as the *Sensor Observation-* (SOS), *Sensor Planning Service* (SPS) and *Sensor Alert Service* (SAS) can be applied. All this data can be integrated, processed and analyzed via one or multiple *OGC Web Processing Service*s (WPS) (OGC-WPS 2007). Such a type of service will contain the effective model for atmospheric simulation, too. In particular raster data, from 2D to 4D (3D + time), can now be (pre-) processed through the new *OGC Web Coverage Processing Service* (WCPS) (OGC-WCPS 2009). Later the visualization of the results can be performed through 3D portrayal services such as *Web 3D Service* (W3DS) (OGC-W3DS) or through projections into 2D, per use of a *Web Map Service* (WMS) (OGC-WMS 2006). The combination of those will be developed and presented in a conceptional schema, outlining the basic interactions within the specification model (s. 3.3.2).
In Summary, we consider this approach as the next logical step towards “Web Processing 2.0”. This way of environmental modeling and in particular for urban-ecology research, making use of interoperable and standardized Spatial-Data-Infrastructures and flexible Web Services, can benefit by this.

2. STATE-OF-THE-ART

Modern *Spatial Data Infrastructures* deliver a broad range of functionalities in order to analyze, edit and visualize geodata and their associated metadata through catalogue services. But up to now the main focus was on distributed data storage in the form of spatial web services. In contrast we propose a more processing oriented approach that includes also distributed and standardized services for analytical purposes. The basic modular design of such web-services, its assets and drawbacks and their current state-of-the-art will

be explained in the following section. In particular the possibility to combine several services more or less dynamically into so called "service chains" needs consideration.
Environmental modeling raises a number of important issues, many of them falling within the domain of GI-Science. As presented here, the will of integrating an atmospheric simulation model has to begin in the field of meteorology. For the reason they had been the first ones creating physical formulas and applying them in models for use in weather prediction already in 1948 (Jacobson 2005). Another group of researchers started early modeling of air flow e.g. around aircrafts (Holt 1977), which is *called Computational Fluid Dynamics* (CFD). In the sector of Earth Sciences, predictive modeling found entrance into climatology (Schneider and Dickinson 1974). The objectives and applied methods of the before mentioned disciplines differ, but the basic concept of applying mathematical formulas in combination with computer based models are similar.
Some possible models, which probably do fit in the proposed concept, will be presented in this chapter. Additionally the demands for those have to be figured out. The scale, for which those are designed for, is one of the main criteria leading to dismiss numerous models. So an overview of model scales is similarly presented and discussed. Their necessary input data is discussed later in section 3.1. Modern modeling systems are iterative, taking a set of initial conditions and applying transformations to obtain a series of predictions, at time intervals stretching into the future (Goodchild 2003). This yields in the necessity to take time as additional model parameter into concern. The term "modeling" is vastly over-loaded, a classification made by Goodchild comprises three subdivisions: the basic "data modeling", second "static modeling". First one covers data management, second examines models managing inputs and transformations into outputs (Goodchild 2003). A simple example for those is the calculation of NDVI (Campbell 2002). The last is termed "dynamic modeling" (Goodchild 2003), which is the relevant class in this work. Those models contain time-dependent processes, described by ordinary differential equations and space- and time dependent processes specified by *Partial Differential Equations* (PDEs) (Jacobson 2005). Solution of these varying equations is made by methods like finite-difference or other approaches (Jacobson 2005). Resuming to the model basics, we will make use of the web services defined by the OGC[1] as follows.

2.1 OGC Web Services (OWS)

The *Open Geospatial Consortium* (OGC)[1] as formation of 382 active members (status: 27.03.09 (OGC members)) is a driving force in definition and leading in standardization of geo-standards. The basics for numerous OGC based web services are given in the *Open Geodata Interoperability Specification* (OGIS) by a broad specification of a software framework for distributed access to geodata and geoprocessing resources (OGC 2006). Mainly addressed is the implementation of services for geodata access, management, manipulation, representation and sharing over computer-networks like local- or wide area networks and of course desktop applications (OGC 2006). In brief an *OGIS Services Model* defines the set of services needed to "access and process the geographic types in the *Open Geodata Model*" (OGC 2006). Supplying capabilities for different and for common sets of geographic feature definitions, to translate between differing ones and to share geodata within user communities. In the following the current OGC standards relevant for realizing interoperable atmospheric modeling will be introduced briefly by a set of common *OpenGIS*® Standards as follows *Web Coverage Service* (raster data), *Web Feature Service* (vector data), *Web Map Service* (map images), *Web processing Service* (geo-processing) and *Web Coverage Processing Service* (raster processing) (OGC-WMS 2006, OGC-WPS 2007, OGC-WCPS 2009). Additionally the services for in situ sensor integration will be introduced on the next page.

---

[1] The OGC is an international organization consisting of academic, governmental and industry organizations who work together in developing open standards for geospatial and location based services (s. www.opengeospatial.org).

2.1.1 OGC Sensor Web Enablement

Returning to the OGC Web Services which come into consideration to cope with integration of the different requested functionalities, starting at the necessity of gaining live in situ measurements of base wind parameters like wind-direction,-speed and air pressure for model input. Such meteorological sensors can be integrated using the OGC *Sensor Web Enablement* (SWE) (OGC-SOS 2007). Those services enable the access to sensor networks and archived sensor data that can be discovered, accessed and if utilizable controlled by standardized interfaces (APIs). Altogether seven *OpenGIS*® Standards compose the SWE suite containing encodings for sensor description and -observation and/or interface definition of web services. Two essential standards which are examined here is the *Sensor Observations Service* (SOS) and *Sensor Planning Service* (SPS). Former delivers a service interface for requesting, filtering and retrieving observations and sensor system information. This is the broker between the client and an observation repository or rather near real-time sensor data (OGC-SOS 2007). The second covers direct requests by users and scheduling the sensor (Botts et al. 2008). Client observation requests are sent from SPS to SOS and the response is returned by SOS beyond SPS to the client. Information contained in the sensor XML can be its state, location and its stored or real-time data (Botts et al. 2008). A complete framework of SWE services under GPL license is provided by *52°North*, based on the programming language JAVA (52°North).

2.1.2 OGC Web Processing Service

A good way for integration of the atmospheric model is the *OGC Web Processing Service* (WPS). This service is able to comprise geoprocessing functionalities or even up to complex processes e.g. a climate change model (OGC-WPS 2007). Multiple processes can be fulfilled by a WPS and even chained if necessary. Delivering standardized interfaces for data input and output, the content of the Processing Service can even be proprietary. Furthermore it is possible to deliver data to it over a network or directly stored on a server. Hiding the atmospheric model behind a Web Processing Service allows flexible use through several clients. Main WPS functionalities comprise the *getCapabilities ()* interface which is defined for all OGC services and service metadata. It is supplemented by the methods *DescribeProcess ()* delivering a detailed description about input and output (interface) of the specific process. *Execute ()* provides effectively running the process and returning the result. One example of a practical OGC and JAVA based WPS framework is available from *lat/lon* called deegree (lat/lon).

2.1.3 OGC Web Catalogue Service

For facilitating the search and location of geographic data and services a *Web Catalogue Service* (CS-W) is necessary in SDIs. The idea behind such a service is to catalogue and share those information's between producers and users of geodata by providing its metadata (OGC 2006).

2.2 Atmospheric models

In reference for all "air-flow" based simulating models, as listed below, the term "atmospheric model" is assigned here as more general term. Two model departments may be distinguished: a) diagnostic and b) prognostic models.
a) First ones are models which are developed by empirically based methods e.g. analyzing real experiments in wind tunnel simulations and converting them into mathematical equations.
b) Prognostic or deterministic models are more exact in such way that they comprise systems of coupled ordinary or *Partial Differential Equations* delivered by *Numerical Weather Prediction Models* (NWP) or

Computational Fluid Dynamics (CFD) models (Jacobson 2005). For the reason that we aim for highly detailed simulation models the latter one's fit our needs. A special fraction, the *Cloud-Resolving Models* (CRM) are excluded here, because they comprehend too much complexity and thus leading to very high demands of computing power. In this stage of development we have not finally chosen a concrete model, instead there is a choice of candidates presented (s. 2.2.2), which fulfill more or less our needs. A short introduction to NWP and CFD models is given here:

Numerical Weather Prediction Models are based on the forecasting of the behavior of atmospheric processes by the numerical solution of the fundamental equations of hydrodynamics, subject to observed initial conditions (Jacobson 2005). Vertical abstraction layers of different depths are applied and additionally the horizontal surface structure is integrated in the higher resolving models by use of *Digital Surface Models* (DSM) plus accounting real orography, land use cover and soil properties (Herzog et al. 2002). *Computational Fluid Dynamics* employ the equations as mentioned for the NWP models. They can be of rather simple structure, just applying the basic physics, up to a sophisticated exactness comprising high box-resolution (from cm to tens of meters) and detailed physical and chemical formula detail (Chung 2003). But instead of having only a couple of layers in vertical extension, they have regular mesh-size in all three dimensions (Chung 2003). Those high level models lead to good results, but in opposite to NWP they are very time consuming in processing (Baklanov 2000). Apart of this barrier, such models would be capable to simulate wind flow over complex surfaces, as demanded, in a high detailed resolution.

2.2.1 Model requirements

The requirements derived by putting following questions on the hypothetic model: Which simulation scales of input data are essential and available in order to simulate air flow for exploration of urban ecology? A city in size of a hundred thousand residents plus a surrounding strip of rural areas. Furthermore how exact should and can be simulated? Additionally which features are worth to have? Taking all facts into concern the requisitions for the model we want, are listed in this top five as follows:

1) Main focused functionality is simulation of air flow for urban-ecology studies e.g. local street canyon turbulence studies, which need a minimum scale smaller than 10 meter range. Ideal would be 1 meter, so bigger trees are in range to be modeled (Bruse 2007).
2) In terms of simulating urban-rural wind-systems a model of about 10 meter up to 100 km is essential.
3) Provided output value (besides model result) in order to be able to quantify model accuracy (RMSE)
4) Integration of near real time in situ sensors, in order to incorporate actual weather information, for more accurate weather modeling. This is the reason why we need to use *Sensor Web Enablement*.
5) A further requisition is that boundary condition input for larger scale meteorological phenomena should be possible e.g. atmospheric inversion as important factor in urban climatology (Seaman 2000).

Result will be in meteorological terms a model covering "Micro-" to "Mesoscale" comprising one meter up to 100 km and preferred time scales will be in the range of minutes up to some days (Jacobson 2005).

2.2.2 NWP and CFD microscale models

As depicted at the beginning of this chapter, the domains of NWP and CFD had a different historical development and both fields of application had been different. But NWP models are approaching higher resolutions especially in horizontal direction, to be able to provide weather forecasts in urban scale (Baklanov et al. 2002). CFDs respectively are disseminating their maximum model area, as computing power is here the restraining factor.

Model	Type, Resolution	Features
LMM	3D micro-scale NWP model, non-hydrostatic com-	Vertical: wind, temperature,

	pressible *Lokal-Modell* (LM), horizontal mesh width Δs=96.5m, vertical up to 3000m with 39 model layers.	humidity. Horizontal: radiation, precipitation, soil properties (Herzog et al. 2002).
ENVI-met ®	3D micro-scale CFD, typ. horizontal resolution 0.5 to 10m and time frame of 24 to 48 hours (time step 10sec at maximum). Max. h/v resolution platform memory depended: 250 x 250 x 25m ~1GB central memory. Multiple-CPU not utilizable.	Buildings, Atmosphere, Soil System, Vegetation, Surfaces, Biometeorology (ENVI-met).
MISKAM	3D micro-scale CFD, horizontal resolution from 1 to 10m, max. area sizes about 1000 x 1000 x 300m	Buildings, Atmosphere, Vegetation (MISKAM).
IBS_CITY	3D micro-scale CFD, numerical Solution of Navier-Stokes differential and of convection-diffusion equation. Concentration variability at wind field calculation is integrated as well. h/v resolution: equidistant and non equidistant depending on computing power from 1 to 100m, max. area size about 100km². Multiple-CPU need special conditions.	Complex 3D building models e.g. pitched or single sided roof shape or building extensions. Model validated by analytical comparative calculation, wind tunnel measurements and natural experiments (IBS_CITY).

Tab. 1 NWP- and CFD microscale model overview

2.2.3 Discussion and Model decision

The investigation in order to find appropriate NWP or CFD models led to four results presented in Tab.1. First one is a representative of NWP, the *LITFASS-Lokal-Modell* (LMM) which is affiliated to the microscale having a horizontal resolution of 96.5m (Herzog et al. 2002). But this is still insufficient for building resolving modeling. The next ENVI-met, is deemed to be not utilizable for Multiple-Processors Systems (ENVI-met), this would prevent up-scaling of simulated model area. MISKAM on the other side has only a few abilities in regard to city-ecology. This means the integration of vegetation and modeling of dry depositions on horizontal planes (MISKAM). Finally a candidate of emission modeling CFD's is IBS_CITY. It is capable to model a three dimensional transient simulation of air pollutant propagation (IBS_CITY). It has a flexible 3D mesh-model, allowing altering scales in all three dimensions. Compared to all candidates presented here, very detailed 3D input is possible. But multi-CPU usage needs special conditions in order to ensure parallelized computing. Therefore the search for an appropriate model has not ended yet.

3. CONCEPT OF SERVICE ARCHITECTURE

The idea of integrating atmospheric models into a SDI in order to increase their interoperability will be put into practice by GI-standards in reference to 2.2. The parts to be taken first into concern are the input data and secondly development of a scheme showing the Model architecture.

3.1 Data preparation

As shown in chapter 2.2.2, different types of input data are necessary to be applied in atmospheric models. For example raster data like simple 2.5D DEM data, or more complex in the case of EnviMet so called "Area Input Files" are required. Another data input could be vector based, like GML based city model structure used for the 3D city model. By this it is possible to represent, store and exchange virtual 3D city and landscape models (OGC-GML 2008). Integration of nearby live sensor data for example delivered by web based meteorological sensors is a third example. Such sensor data e.g. from single measurements of rotating-cup anemometers (wind speed) have to be checked for accuracy and converted into a wind field map. In order to use this data for numerical predictions it is necessary to preprocess the input data, by combination of atmospheric behavior as codified in the computer models, thus producing a “best” estimate of current conditions (Schlatter 2000). Finally taking into concept, the need for keeping a survey of the different input datasets stored in different databases, storing of metadata should be managed by a *Web Catalogue Service*. The OGC Web Service composition is presented in the following paragraph.

3.2 OWS composition

State of the art geoprocessing is still based on geodatabase and desktop GIS. For the central component of processing there will be the *Web Processing Service* acquiring the right input data, computing the model and preparing the output for visualization. Depending on the chosen simulation model some services won’t be needed for example simple models like *Envi-met* who afford as basic input data raster- instead of vector data (ENVI-met). Preparation of input, as requested by the model, can be realized through the *Web Coverage Processing Service*. Vector and Sensor data can be directly delivered by WFS respectively SWE. Given the chance of regarding any *OGC Web Service* as a “Black box” (OGC 2001) the real WPS functionality inside it is not considered here. Finally the necessity to prepare the output data for 2D- or 3D portrayal services should be managed. The basic concept of the desired interaction between those different services is shown in 3.2.1.

3.2.1 SDI model integration

In consequence the implementation structure of those loosely bound services (*Service Oriented Architecture* SOA) requires an orchestration in order to organize the concrete workflow. As you are shown here, the Web Processing Service in the center will manage the different inputs and enables output in a first step as 2D- and later on as 3D-visualizations. Such a combination of planned services here is offered by the concept of a Composite-WPS (Stollberg and Zipf 2007). On the right-hand a second WPS just for the atmospheric model, is planned too. This is for the reason of encapsulating the model dependent processes like analysis and modeling.

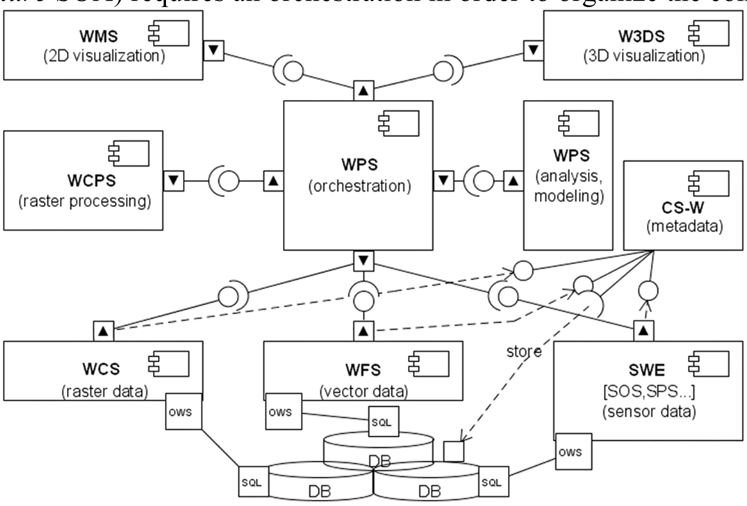

Fig. 1 UML component diagram – proposed SDI integration

3.3 DISCUSSION

Accomplished steps for construction of previous preliminary SDI-OWS integration schema had been executed by identifying the concrete processes, analyzing the required intermediate interaction (communication) and the point of data preparation. The latter shows the advantages of having standardized data formats like City GML. This will help to ensure interoperability and future enhancements. In the domain of creation of new OGC standards a new group called "Meteorology Domain Working Group" formed itself in November 2008 to standardize in a first step the (model-) data-interchange between the different meteorological workgroups (OGC-METEO 2009). The challenge for choosing the adequate atmospheric model, fulfilling the mentioned requirements, has not yet led to a final answer. But the one of choice will likely be a CFD, because of higher resolutions enabling also the integration of single trees (Bruse 2007).

4. CONCLUSION

This paper proposed eminent interesting topics as planning the integration of an atmospheric model in use of *OGC Web Services* and creating a concept for using also detailed 3D city models in realm of urban-ecologic simulation. Our research resulted so far in an abstract schema for an integration of atmospheric models of a certain scale into SDI by applying OGC standards. One of the next steps is to locate a suitable model and a prototypical realization in order to find general principles of service integration. In future work one or two candidates of atmospheric models will be selected, integrated into a SDI and checked. Further scientific questions concerning e.g. urban ecological- or emission modeling will have to be expressed, too.

Along the conclusions, drawn from this research, the feasibility of this proposal and a definition of best practices for similar environmental simulation models were shown. In summary GI-standards are beneficial and reasonable for atmospheric models, too. Due to this presented web- and standards- based approach flexibility is given by interoperability and scalability, just as well as extensibility.

5. Literature

52°North: 52°North Initiative for Geospatial OSS GmbH: Sensor Web Community, Internet: http://52north.org/index.php?option=com_content&view=category&layout=blog&id=15&Itemid=19, last access: 25.03.2009.

Baklanov, A., Rasmussen, A., Fay, B., Berge, E. and Finardi, S. (2002): Potential and shortcomings of numerical weather prediction models in providing meteorological data for urban air pollution forecasting, in Water, Air, & Soil Pollution: Focus, Springer, Netherlands, Vol. 2, Nr. 5-6 / Sept. 2002, pp. 43-60.

Baklanov, A. (2000): Application of CFD Methods for Modelling in Air Pollution Problems: Possibilities and Gaps, Environmental Monitoring and Assessment, Springer, Netherlands, Vol. 65, Nr. 1-2 / Nov. 2000, pp. 181-189.

Best, M. J. (2005): Boundary-Layer Meteorology, Springer, Netherlands, Volume 114, Issue 1 / January 2005, pp. 91-109.

Botts, M., Percivall, G., Reed, C. and Davidson, J. (2008): OGC® Sensor Web Enablement: Overview and High Level A., Lecture Notes in Computer Science, Vol. 4540, Springer Berlin/Heidelberg, pp. 175-190.

Bruse, M. (2007): Simulating human thermal comfort and resulting usage patterns of urban open spaces with a Multi-agent System, Proceedings of the 24th International Conference on Passive and Low Energy Architecture PLEA, p.699-706.

Campbell, J. B. (2002): Introduction to remote sensing, Guilford Press, New York (et al.), 4th edition.

Chung, T. J. (2003): Computational fluid dynamics, Cambridge Univ. Press (et al.), Cambridge.

ENVI-met: Bruse, M. & team: ENVI-met Model Architecture version 3, Internet: http://www.envi-met.com/architecture.htm, last access: 03.04.2009.

lat/lon: lat/lon GmbH: deegree Java Framework, Internet: http://deegree.org, last access: 22.03.2009.

MISKAM: Ingenieurbüro Lohmeyer GmbH & Co. KG: Manual MISKAM, Internet: http://www.lohmeyer.de/eng/Software/zip/MISKAM%205%20Manual_English.pdf, revision 06/2008.
Goodchild, M. F. (2003): Geographic information science and systems for environmental management, Annual Reviews of Environment and Resources 28: 493–519.
GDI-DE: Geodateninfrastruktur Deutschland, Internet: http://www.gdi-de.de/de/inspire/f_inspire.html, last access: 02.04.2009.
Herzog, H.-J., Vogel, G. and Schubert, U. (2002): LLM – a nonhydrostatic model applied to high-resolving simulations of turbulent fluxes over heterogeneous terrain, Theoretical and Applied Climatology, Springer, Wien, Volume73, Numbers 1-2 / Dezember 2002, pp. 67-86.
Holt, M. (1977): Numerical methods in fluid dynamics, Springer Series in computational physics, Springer, Berlin.
IBS_CITY: IBS Ingenieurbüro für Umweltschutz und Strömungstechnik: Personal Request of model descriptions, IBS_CITY_K.pdf & IBS_CITY_IMM_LIMA.pdf & IBS_CITY_VER.pdf, 2008/2009.
OGC (2001): Introduction to OGC Web Services, white paper, editors: Doyle, A. and Reed, C.
OGC (2006): Buehler, K., McKee, L, The OpenGIS® Guide (third edition), Technical Committee, version 1, Engineering Specification Best Practices, OGIS TC Doc. 96-001.
OGC-GML (2008): OpenGIS® City Geography Markup Language, Encoding Standard Document Reference Number: 08-007r1, version 1.0.0, editors: Gröger, G., Kolbe, T. H., Czerwinski, A. and Nagel, C.
OGC members: Open Geospatial Consortium members, Internet: http://www.opengeospatial.org/ogc/members, last access: 27.03.2009.
OGC-METEO (2009): Meteorology DWG Charter, Pending Document, Document Reference Number 09-027, editors: Little, C. and Woolf, A.
OGC-SENSOR (2009): Sensor Web Enablement Working Group, Internet: http://www.opengeospatial.org/projects/groups/sensorweb, last access: 02.04.2009.
OGC-SOS (2007): OpenGIS® Sensor Observation Service. Abstract Specification, Document Reference Number 06-009r6, version 1.0.0, editors: Na, A. and Priest, M.
OGC-W3DS (2005): Web 3D Service. Discussion Paper, Document Reference Number 05-019, version 2, editors: Quadt, U., Kolbe, T. H.
OGC-WCPS (2009): OpenGIS® Web Coverage Processing Service (WCPS), Language Interface Standard, Document Reference Number: 08-068r2, version 1.0.0, editor: Baumann, P.
OGC-WMS (2006): OpenGIS® Web Map Server, Implementation Specification, Document Reference Number 03-109r1, version 1.3.0, editor: Beaujardiere, J.
OGC-WPS (2007): Web Processing Service. OpenGIS® Standard, Document Reference Number 05-007r7, version 1.0.0, editor: Schut, P.
Jacobson, M. Z. (2005): Fundamentals of Atmospheric Modeling, second edition, Cambridge Univ. Press, Cambridge.
Seaman, N. (2000): Meteorological modeling for air-quality assessments. Atmospheric Environment 34 (2000), pp. 2231–2259.
Schlatter, T. W. (2000): Variational assimilation of meteorological observations in the lower atmosphere: A tutorial on how it works, Journal of Atmospheric and Solar-Terrestrial Physics, Elsevier, Volume 62, Issue 12, pp. 1057-1070.
Schneider, S. H. and Dickinson, R. E. (1974): Climate Modeling, Rev. of Geophysics, 12(3), pp. 447–493.
Steppeler, J., Hess, R., Schättler, U. and Bonaventura, L. (2003): Review of numerical methods for non-hydrostatic weather prediction models, Meteorology and Atmospheric Physics, Springer, Wien, Volume 82, Numbers 1-4 / Januar 2003, pp. 287-301.
Stollberg B., Zipf A. (2007): OGC Web Processing Service Interface for Web Service Orchestration: Aggregating geo-processing services in a bomb threat scenario, W2GIS 2007. Cardiff, UK.

Walenciak, G., Stollberg, B., Neubauer, S. and Zipf, A. (2009): Extending Spatial Data Infrastructures 3D by Geoprocessing Functionality: 3D Simulations in Disaster Management and environmental Research, GEOWS 2009, Cancun. Mexico.