Contribution to ESF Exploratory Workshop „Exploring Epistemic Shifts in Computer-Based Environmental Sciences"

Instruments and Simulations at DLR-IPA since 1962: A participant's perspective

by Hans Volkert *Hans.Volkert@DLR.de*

Deutsches Zentrum für Luft- und Raumfahrt (DLR)
Institut für Physik der Atmosphäre (IPA)
D-82234 Oberpfaffenhofen, G e r m a n y

1. Introduction

The general development of institutions dealing with aerodynamic research in Germany during the 20th century is well documented, with a special emphasis on institutes embedded within what has been carrying the name *Deutsches Zentrum für Luft- und Raumfahrt* (DLR) since 1989. Already in 1966 *atmospheric physics* was mentioned as an important research area (Trischler 1992, p. 449). Likewise the general aim of an "appropriate blend between theory and practical work" (i.e. experimentation) within an autonomous selection of research tasks by the acting scientists was repeatedly formulated (Trischler 2007; p. 210). However, an in-depth juxtaposition of achievements along the strands of experimentation, of theoretical reasoning as well as about the development and application of simulation models as a combination of the former two is lacking, at least with regard to atmospheric processes.

This exploratory contribution takes the *Institut für Physik der Atmosphäre* (IPA) of DLR as a prototypical research institute. The institute was founded at the airport of München-Riem on 1 July 1962 under this quite general name as a merger from two more specialized smaller institutes. The name is being kept until today, even though the parent organisation changed status and/or full name no less than fives times. Under the partly cooperative guidance by only four directors (Prof. Hans-Gerhard MÜLLER, 1962-1972; Prof. Heinz FORTAK, 1973-1976; Dr. Manfred E. REINHARDT, 1974-1992; Prof. Ulrich SCHUMANN, since 1982) a gradual increase took place in categories like scientific staff, areas of expertise, visibility through refereed publications, number of graduate and post-doctoral students, breadth and intensity of international cooperation. Here, an attempt is made to sketch by some examples, how experimental and theoretical work got better integrated over the years arriving at numerical simulations as an integrative tool for basic and applied research problems.

This brief exposition first collects groups of key instruments developed and used at IPA, and then highlights theoretical approaches and the application of simulation models. It follows a sketch of the author's – certainly arbitrary – personal trajectory spanning three decades in an attempt to demonstrate that nowadays progress necessitates a tight cooperation interweaving the mentioned categories. In combination with the referenced research papers, the concluding remarks may help to set the scene for more systematic science-historical studies in the future.

2. Groups of key instruments

During the 1960s, the initial focus of research at IPA laid in experimental studies, comprising partly the instrumentation of small airplanes with *in-situ* data acquisition systems, partly in ground-based equipment for local weather modification, e.g. clearing fog at airports.

Within IPA's second decade, the different categories of remote sensing techniques started to be implemented as well. These comprised *passive* methods – measuring radiation at solar and terrestrial wavelengths, respectively – at the ground and aboard novel satellites as well as *active* techniques – sending and receiving wave-packets in the microwave (radar: **ra**dio **d**etection **a**nd **r**anging) or visible regimes (lidar: **li**ght **d**etection **a**nd **r**anging). Radar measurements of precipitation complexes allowed to document the life cycle of convective precipitation events (often thunderstorms) from a single fixed position (e.g. Singler 1977). After the installation of a polarimetric-Doppler-radar on IPA's roof in 1985, the motion of precipitation cells and a classification of hydrometeors became possible (e.g. Schroth et al. 1988). Upward-pointing lidar measurements help to determine elevation and thickness of layers of enhanced aerosol concentrations (Kent et al. 1979). The successful miniaturization of lidar systems made possible their integration into the research jet aircraft *Falcon* (acquired 1976; cf. e.g. Ehret el al. 1998) and a multitude of missions during coordinated campaigns, often with a broad international participation (e.g. Hoinka et al 2003; Reitebuch et al. 2003).

All remote sensing techniques necessitate complex retrieval algorithms that allow to determine the desired basic meteorological parameters from the original measurements of radiation, or the small proportion of backscattered pulse energy combined with the time delay between emission and reception. These in turn are firmly rooted in theoretical concepts and often have significant computational demands, ideally in near real-time. More generally, atmospheric physics or meteorology have to take a *synoptic* perspective by integrating observations from a multitude of sources. The primitive (i.e. basic) equations of geophysical fluid dynamics serve increasingly as consistent backbone.

3. Theory and simulation models

From 1974 to 1992 a co-directorship at IPA explicitly underscored the aim of strongly linking experimental investigations (overseen by M.E.Reinhardt; 1974-92) with theoretically founded simulations (steered by H. Fortak, 1973-76, and U. Schumann since 1982).

Combining measurements obtained by instrumented motor-gliders in the vicinity of large power stations with dispersion modelling formed an early first coordinated effort. During the late 1970s hydro-static simulation codes for mesoscale simulations were imported from the USA and applied to idealized as well as realistic studies of airflow over mountain ranges as the Alps or the Dinaric Alps (e.g. Hoinka 1985). The development of a quite general non-hydrostatic code termed MESOSCOP started in 1983 (Schumann et al. 1987), which was applied for numerous studies, e.g. in areas as turbulence, cloud formation and stratospheric cooling due to mountain waves (Volkert and Intes 1992). Later on, the implementation of mesoscale modelling system with grid nesting allowed realistic episode simulations for field campaigns in forecast or analysis mode (e.g. Leutbecher and Volkert 1996; Dörnbrack et al. 1998; Volkert et al. 2003).

Since 1992, global climate scenario simulations including chemical processes (e.g. Dameris 1995) have helped to assess the relative importance of stratospheric ozone, condensation trails (e.g. Schumann 2005) and ice clouds. Such tools also became essential for an impact assessment of components of the global transportation system as aviation or shipping on the global climate. Multi-year retrievals from polar orbiting satellites experiments as GOME provided validation data for the global simulations.

4. A personal trajectory through three decades

At present some 60 scientists work at IPA who hold a university degree and a doctorate in disciplines like mathematics, physics, meteorology, geophysics, chemistry or civil engineering. Additional scientific and technical support staff as well as graduate and under-graduate students bring the full work force to about 160 persons. While most of the scientists got their basic training in either experimentally orientated or more theoretical studies, many act on both sides of the "experiment-theory-divide" during different periods of their careers.

The sequence of activities, the author of this account was involved in, may serve as an arbitrary, though illustrative example. He first joined IPA in September 1980 and worked as a PhD student applying novel techniques for conventional climate observations (Volkert 1985). His tasks as post-doctoral researcher from 1983 laid on the theoretical and numerical side within the development team of a general simulation code for basic research studies in the mesoscale (Schumann et al. 1987). As a staff scientist from 1986 onwards he contributed to the coordination of various international field campaigns, e.g. the *Front Experiment* (1987; Hoinka and Volkert 1987; Volkert et al. 1991), the Special Observing Period of the Mesoscale Alpine Programme (MAP-SOP in 1999; Bougeault et al. 2001; Volkert and Gutermann 2007) and the *Convective and Orographically-induced Precipitation Study* (COPS in 2007; Wulfmeyer et al., 2007).

The evolution of the topic *stratospheric mountain waves* during the 1990s indicates how a close linkage of theoretical investigations with fresh experimental findings advances both understanding and tailored guidance for further experimental campaigns. Partly idealized, two-dimensional simulations of flow across the Scandinavian mountain gave strong indication that vertically propagating waves provide a mesoscale cooling mechanism to reconcile balloon measurements of temperature with the modelled ones along hemispheric trajectories for heights up to 27 km (Volkert and Intes 1992). Taylored, three-dimensional hindcast simulations with a weather forecasting research model corroborated the initial assumption (Leutbecher and Volkert 1996). After a switch from analysis to forecast mode and the temporal establishment of a real-time data link to the global forecasting model of Deutscher Wetterdienst, the predicted mesoscale temperature anomalies could indeed be inferred from airborne, upward-looking lidar observations. Amidst the darkness of the polar night structures of high relevance for ozone destruction in the stratosphere could be detected at the anticipated time and location, as if a missed needle was found in a stack of hay (Dörnbrack et al 1998). These experiences spawned a broad variety of studies where a hierarchy of idealized to realistic simulations link theoretical concepts with observational evidence (e.g. Volkert et al. 2003).

5. Conclusions

Atmospheric physics and meteorology underwent a dramatic development during the past 50 years, not the least induced by the increase in computing power, the installation of truly global observation systems (e.g. a fleet of polar orbiting and geo-stationary satellites) and by a growing number of fulltime staff at various institutions, who are able and willing to build teams with a broad variety of backgrounds. The growing necessity of international cooperation on a voluntary basis is seen as one katalytical ingredient for progress (the interlinked topics of Radiation & Ozone were recently surveyed as an illustrative example; Ohring et al. 2009). It appears that the epistemic distinction between theory and observation is gradually shifted. It remains to be determined whether the introduction of sophisticated simulation experiments forms a third intermediate category or whether an integrated picture of *observation-simulation-theory* parallel to the general activities *looking-diagnosing-understanding* provide a better depiction of the current scientific process, as paradigmatically depicted by Shapiro (1994). The DLR-Institut für Physik der Atmosphäre as well as its retired and current staff are ready to provide background material from 1962 onwards for such an undertaking.

References

Bougeault, P., P. Binder, A. Buzzi, R. Dirks, R. Houze, J. Kuettner, R.B. Smith, R. Steinacker and H. Volkert, 2001: The MAP special observing period. *Bull. Amer. Meteorol. Soc.* **82**, 433–462.

Dameris, M., 1995: Coupling of dynamical and chemical processes in GCMs. *Phys. Chem. Earth* **20**, 53-61.

Dörnbrack, A., M. Leutbecher, H. Volkert and M. Wirth, 1998: Mesoscale forecasts of stratospheric mountain waves. *Meteorol. Appl.* **5**, 117–126.

Ehret, G., A. Fix, V. Weiss, G. Poberaj and T. Baumert, 1998: Diode-laser.seeded optical parametric oscillator for airborne water vapour DIAL applications in the upper troposphere and lower stratosphere. *Appl. Phys. B* **67**, 427-431.

Hoinka, K.P., 1985: A comparison of numerical simulations of hydrostatic flow over mountains with observations*.* *Mon Wea. Rev.* **113**, 719-735.

Hoinka, K.P., E. Richard, G. Poberaj, R. Busen, J.-L. Caccia, A. Fix and H. Mannstein, 2003: Analysis of a potential-vorticity streamer crossing the Alps during MAP IOP 15 on 6 November 1999. *Quart. J. Roy. Meteorol. Soc.* **129**, 609–632.

Hoinka, K.P. and H. Volkert, 1987: The German front experiment. *Bull. Amer. Meteorol. Soc.* **68**, 1424-1427.

Kent, G.S., F. Köpp, C. Werner, 1979: A joint lidar solar radiometer experiment. *J. Appl. Meteorol.* **18**, 1649–1655.

Leutbecher, M. and H. Volkert, 1996: Stratospheric temperature anomalies and mountain waves: A three-dimensional simulation using a multi-scale weather prediction model. *Geophys. Res. Lett.* **23**, 3329–3332.

Ohring, G., R. Bojkov, H.-J. Bolle, R. Hudson and H. Volkert, 2009: Radiation and ozone - Catalysts for advancing international atmospheric science programs for over half a century. *Bull. Amer. Meteorol. Soc.* **90**, 1669-1681; DOI:10.1175/2009BAMS2766.1

Reitebuch, O., H. Volkert, C. Werner, A. Dabas, P. Delville, P. Drobinski, P.H. Flamant and E. Richard, 2003: Determination of airflow across the Alpine ridge by a combination of airborne Doppler lidar, routine radiosounding and numerical simulation. *Quart. J. Roy. Meteorol. Soc.* **129**, 715–727.

Schumann, U., T. Hauf, H. Höller, H. Schmidt and H. Volkert, 1987: A mesoscale model for the simulation of turbulence, clouds and flow over mountains: Formulation and validation examples. *Beitr. Phys. Atmosph*. **60**, 413–446.

Schumann, U., 2005: Formation, Properties and Climate Effects of Contrails. *Comptes Rendus Physique* **6**, 549-565. DOI: 10.1016/j.crhy.2005.05.002.

Singler, A., 1977: Wachstumsgeschwindigkeit und Lebensdauer konvektiver Niederschlagswolken. *Arch. Met. Geophys. Biokl., Ser. A,* **24**, 33-39.

Schroth, A., M. Chandra and P. Meischner, 1988: A C-band coherent polarimetric radar for propagation and cloud physics research. *J. Atmos. Ocean. Tech.* **5**, 803-822.

Shapiro, M.A., 1994: Paradigmatic depiction of scientific inquiry. Back covers of Proceeding Volumes *Life cycles of extratropical cyclones*' Geophys. Inst. Univ. Bergen, Norway., ISBN 82-419-0144-5.

Trischler, H., 1992: *Luft- und Raumfahrtforschung in Deutschland 1900-1970: Politische Geschichte einer Wissenschaft.* Campus Verlag, Frankfurt, ISBN 3-593-34586-2, 542 pp.

Trischler, H., 2007: Auf der Suche nach institutioneller Stabilität: Luft- und Raumfahrtforschung in der Bundesrepublik Deutschland. In: H. Trischler & K.U. Schrogl: *Ein Jahrhundert im Flug: Luft- und Raumfahrtforschung in Deutschland 1907-2007*. Campus Verlag, Frankfurt, 195-210.

Volkert, H.. 1985: On the mesoscale variability of meteorological fields - the example of Southern Bavaria. *Beitr. Phys. Atmosph*. **58**, 498–516.

Volkert, H. and T. Gutermann, 2007: Inter-domain cooperation for mesoscale atmospheric laboratories: The Mesoscale Alpine Programme as a rich study case. *Quart. J. R. Meteorol. Soc.* **133**, issue 625, 949-967; DOI: 10.1002/qj.95

Volkert, H. and D. Intes, 1992: Orographically forced stratospheric waves over northern Scandinavia. *Geophys. Res. Lett.* **19**, 1205–1208.

Volkert, H., C. Keil, C. Kiemle, G. Poberaj, J.-P. Chaboureau and E. Richard, 2003: Gravity waves over the eastern Alps: A synopsis of the 25 October 1999 event IOP10) combining in-situ and remote measurements with a high-resolution numerical simulation. *Quart. J. Roy. Meteorol. Soc.* **129**, 777–797.

Volkert, H., L. Weickmann and A. Tafferner, 1991: The 'papal front' of 3 May 1987 – a remarkable example of frontogenesis near the Alps. *Quart. J. Roy. Meteorol. Soc.* **117**, 125–150.

Wulfmeyer, V., A. Behrendt, H.-S. Bauer, C. Kottmeier, U. Corsmeier, A. Blyth, G.C. Craig, U. Schumann, M. Hagen, S. Crewell, P. di Girolamo, C. Flamant, M. Miller, A. Montani, S. Mobbs, E. Richard, M.W. Rotach, M. Arpagaus, H. Russchenberg, P. Schlüssel, M. König, V. Gärtner, R. Steinacker, M. Dorninger, D.D. Turner, T. Weckwerth, A. Hense, C. Simmer, 2008: The Convective and Orographically-induced Precipitation Study. *Bull. Amer. Meteorol. Soc*. **89**, 1477-1486