HErZ

The German Hans-Ertel Centre for Weather Research

BY CLEMENS SIMMER, GERHARD ADRIAN, SARAH JONES, VOLKMAR WIRTH, MARTIN GÖBER, CATHY HOHENEGGER, TIJANA JANJIĆ, JAN KELLER, CHRISTIAN OHLWEIN, AXEL SEIFERT, SILKE TRÖMEL, THORSTEN ULBRICH, KATHRIN WAPLER, MARTIN WEISSMANN, JULIA KELLER, MATTHIEU MASBOU, STEFANIE MEILINGER, NICOLE RIß, ANNIKA SCHOMBURG, ARND VORMANN, AND CHRISTA WEINGÄRTNER

German universities are partnering with the German Weather Service to more effectively link basic research and teaching in atmospheric sciences with the challenges of operational weather forecasting and climate monitoring.

Fundamental research addressing the challenges of weather forecasting is required in order to steadily improve the quality of weather forecasts and climate monitoring. The potential for such research to be translated into operational advances is increased significantly if carried out in collaboration with the national meteorological and hydrometeorological service (NMHS; acronyms are listed in the appendix) of the country in question. To this end, the Hans-Ertel Centre for Weather Research (HErZ; www.dwd.de/ertel-zentrum) was established in 2011 as a virtual center that develops and organizes a lasting cooperation along common research objectives between the German Weather Service [Deutscher Wetterdienst (DWD)] and German universities and research institutions. The focus of HErZ is on basic research. The concept foresees that the knowledge and understanding gained through HErZ will be transitioned into operations over a time scale of about 10 years. Prior to the establishment of the Hans-Ertel

AFFILIATIONS: SIMMER—Rheinische Friedrich-Wilhelms-Universität Bonn, Bonn, Germany; ADRIAN, JONES, JULIA KELLER, MASBOU, RIß, SCHOMBURG, VORMANN, AND WEINGÄRTNER—Deutscher Wetterdienst, Offenbach, Germany; WIRTH—Johannes Gutenberg-Universität Mainz, Mainz, Germany; GÖBER, JANJIĆ, JAN KELLER, SEIFERT, AND WAPLER—Deutscher Wetterdienst, Offenbach, and Hans-Ertel Centre for Weather Research, Germany; HOHENEGGER—Hans-Ertel Centre for Weather Research, and Max Planck Institute for Meteorology Hamburg, Hamburg, Germany; OHLWEIN AND TRÖMEL—Rheinische Friedrich-Wilhelms-Universität Bonn, Bonn, and Hans-Ertel Centre for Weather Research, Germany; ULBRICH—Hans-Ertel Centre for Weather Research, and Freie Universität Berlin, Berlin, Germany; WEISSMANN—Hans-Ertel Centre for Weather Research, and Ludwig-Maximilians-Universität München, München, Germany; MEILINGER—Deutscher Wetterdienst, Offenbach, and Hochschule Bonn-Rhein-Sieg, Sankt Augustin, Germany

CORRESPONDING AUTHOR: Sarah Jones, Deutscher Wetterdienst, Frankfurterstr. 135, 63067 Offenbach, Germany
E-mail: sarah.jones@dwd.de

The abstract for this article can be found in this issue, following the table of contents.
DOI:10.1175/BAMS-D-13-00227.1

In final form 23 August 2015

Centre, the only practicable source of funding in Germany for advancing weather forecasting and climate monitoring was the German Research Foundation (DFG). The Federal Ministry for Research and Education (BMBF), the main funding organization for more applied science in Germany, only very reluctantly funds research on weather forecasting because the DWD belongs to the Federal Ministry of Transport and Digital Infrastructure (BMVI, formerly BMVBS). Until recently this ministry did not provide research funds that enabled the DWD to support extramural research. This situation gradually led to a detachment of academia and research centers from the DWD. The situation improved somewhat through the establishment of the DFG-funded special priority program on improving quantitative precipitation forecasting between 2004 and 2010 (Hense and Wulfmeyer 2008; Wulfmeyer et al. 2008) that united almost all German weather-related research institutes with the DWD. The very positive experiences from this community effort, during which DWD gave access to its model and data assimilation system, provided the impetus for the establishment of a long-term formalized cooperation platform and was a catalyst for the development of HErZ.

WEATHER RESEARCH IN EUROPE. In Europe three NMHSs (France, Germany, and the United Kingdom) maintain global and regional numerical weather prediction (NWP) facilities while more than 25 smaller NMHSs only run high-resolution regional systems; all cooperate operationally via the European Meteorological Network (EUMETNET; www.eumetnet.eu/). There are 20 European states that finance the European Centre for Medium-Range Weather Forecasts (ECMWF), which is governed by representatives of the NMHSs of its member states. Regional NWP development is conducted for the most part in four regional modeling consortia [ALADIN (www.cnrm.meteo.fr/aladin/), COSMO (www.cosmo-model.org/), HIRLAM (www.hirlam.org/), and Met Office (www.metoffice.gov.uk/)]. Their modeling systems are all used as research tools in the academic community. A wide range of strategies exists in Europe for the cooperation between academia and the respective NMHS. In the following, we give three prominent examples and contrast them with the situation in Germany before the Hans-Ertel Centre was founded.

In France, the national weather service, Météo-France, has a long-standing partnership with the Centre National de la Recherche Scientifique (CNRS), the main national research organization. Resources are pooled between both institutions for the funding of oceanic and atmospheric research programs. In addition, there are a number of joint ventures that Météo-France cofunds with other research organizations and industrial partners. Examples are the French Centre National de Recherches Météorologiques (CNRM), the tropical cyclone research laboratory in La Réunion (cooperation with the University of La Réunion), the service of French instrumented airplanes in environmental research (in cooperation with the French National Space Centre), and the European Research Centre for the Advancement of Scientific Computing.

In the United Kingdom, the pioneer operational–academic partnership for weather research was the Met Office–University of Reading Joint Centre for Mesoscale Meteorology, established in 1987 as a Met Office group within the University Department of Meteorology. In 2009, the Natural Environment Research Council (NERC) and the Met Office established the Joint Weather and Climate Research Programme to sustain and enhance the United Kingdom's research and infrastructure for observing, modeling, and predicting weather and climate and to ensure pull-through into the delivery of services to government and industry. This program oversees the major jointly owned infrastructure such as the Facility for Airborne Atmospheric Measurements (FAAM) and the Met Office and NERC joint supercomputer system (MONSooN). More recently, the more structured Met Office Academic Partnership was introduced between the Met Office and the universities of Exeter, Leeds, Oxford, and Reading. The partnership introduced various mechanisms to coordinate science including the Met Office investing in jointly funded chairs at these universities.

In Switzerland, the Federal Office of Meteorology and Climatology, MeteoSwiss, has a long-standing cooperation with the Federal Institute of Technology [Eidgenössische Technische Hochschule (ETH) Zürich] and several other universities facilitated by national research programs, funded by the Swiss Science Foundation (SNF). The largest program was the Swiss National Centre of Excellence in Research on Climate, a collaborative 12-yr (2001–13) multi-institutional program addressing "Climate Variability, Predictability, and Climate Risks," which led to the creation of two research centers. The "Center for Climate Systems Modeling" (www.c2sm.ethz.ch) is funded primarily by ETH Zürich and MeteoSwiss (with three additional partners) and has become central for many joint activities including projects with the Swiss National Super Computing Centre. MeteoSwiss runs its COSMO model suite at this center and has several research projects related to the new high-performance

THE CENTRE IS NAMED AFTER HANS ERTEL

Hans Richard Max Ertel (Fig. SB1), a very influential scientist in the twentieth century, carried out ground-breaking work in the field of fluid dynamics, especially on the concept of potential vorticity (Fortak 2004). The corresponding theorem named after him (Ertel 1942) generated numerous follow-up studies that explored the rich properties of the potential vorticity concept, first seen and interpreted by him (Claussen and Hantel 2004). He was born 24 March 1904 in Berlin and died 2 July 1971. After working in a bank, as a factory engineer, and an assistant to the librarian at the Meteorological Institute in Berlin, he studied mathematics, natural sciences, and philosophy in Berlin, where he finished his Ph.D. in 1932. He became professor and director of the Institute for Meteorology and Geophysics of the University of Innsbruck, Austria, between 1943 and 1945 but returned to Berlin as a professor at the Institute for Meteorology and Geophysics at the Humboldt University Berlin until his retirement in 1969. A tribute to Hans Ertel on the 100th anniversary of his birth including English translations of his scientific publications can be found in the *Meteorologische Zeitschrift* [Vol. 13 (6), December 2004].

Fig. SB1. Picture of Hans Ertel, taken in spring 1970. (Courtesy of Heinz Fortak, Berlin.)

computer architecture and the use of graphics processing units (GPUs) in weather and climate modeling. A joint professorship with ETH Zürich is planned also.

Before the Hans-Ertel Centre was founded, the research cooperation between DWD and academia took place predominantly in individual research projects and through the provision of DWD tools and data along with advice on their use. These collaborations were mostly driven by the needs of individual research projects rather than DWD strategic planning. Exceptions to this were the provision and support of the COSMO model (Baldauf et al. 2011) for research and the partnership with the Max Planck Institute (MPI) for Meteorology to develop the new global-to-regional modeling system ICON (Zängl et al. 2015). A program of extramural research funding allowed DWD to tap into the expertise in the academic community to assist in the pull-through of fundamental research results to operations.

DEVELOPMENT AND ESTABLISHMENT OF THE HANS-ERTEL CENTRE. The DWD was reviewed in 2005 by the Wissenschaftsrat (Council of Science and Humanities), one of the leading independent science policy advisory bodies to the German government. The council confirmed that DWD research was very good to excellent in specific areas but identified a need for stronger cooperation with academia in research, education, and training that went beyond the provision of models and data. The DWD scientific advisory board concluded in 2006 that the DWD was falling behind the leading European NMHSs in terms of forecast quality and identified the lack of in-house fundamental research and an increasing detachment of research at universities and research centers from DWD needs as major obstacles to progress. The board recommended a common fundamental research program of DWD with academia oriented toward the requirements of weather prediction and climate monitoring that would allow a significant part of the German atmospheric research community to conduct the fundamental and transitional research that cannot be carried out at DWD. A DFG-funded roundtable discussion, attended by about 40 scientists including senior researchers at DWD and representatives of the relevant funding agencies, took place in 2007. The participants compiled the challenges for future weather prediction and climate monitoring in

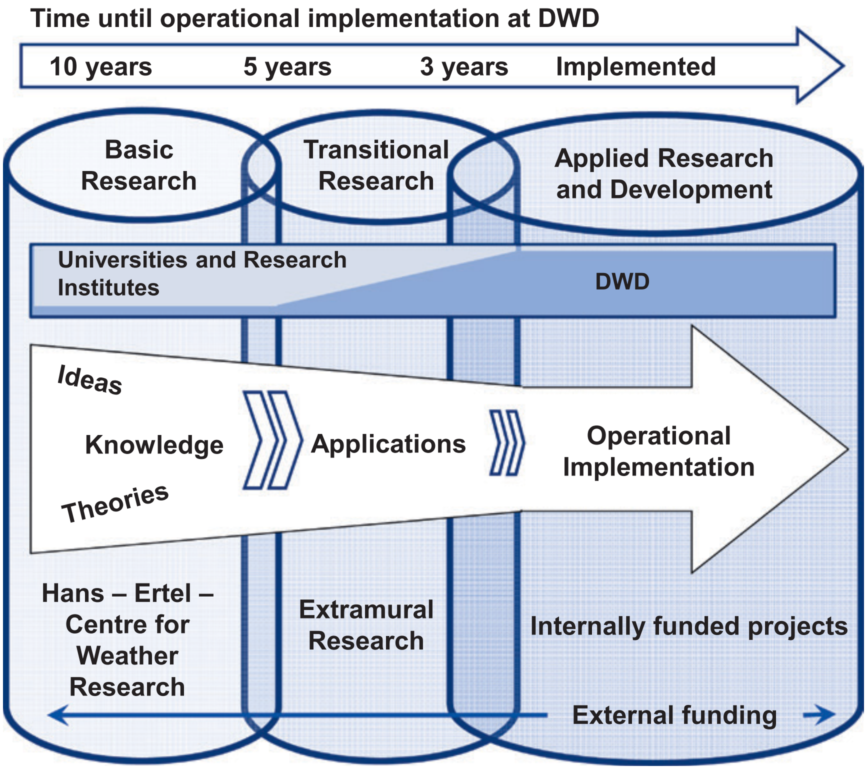

Fig. 1. Three-pillar research strategy of DWD.

a NMHS currently underrepresented in the German research landscape, namely, weather forecasting and climate monitoring.

For the development of the Hans-Ertel Centre, a 12-yr core funding period of three 4-yr phases is foreseen, during which the participating research groups must achieve structural and financial sustainability. The DFG Transregional Collaborative Research Centres serve as a blueprint for HErZ. These centers aim to bundle expertise dispersed over several universities for the advancement of a central research topic. The HErZ research groups, or branches, are led jointly by an academic scientist and a DWD scientist. Each research group receives core funding of around €300,000 yr^{-1}. Additional funding supports the DWD staff members, networking, and administration. The dual leadership (Fig. 2) ensures that HErZ research stays aligned to DWD needs and allows DWD staff members to gain experience working in a university environment. Through the research and teaching carried out within HErZ,

a white paper that contained as a central element the research and development plan for HErZ, named after Hans Ertel, a famous German meteorologist of the last century (see the sidebar on Hans Ertel). Since DWD is a federal agency of the BMVI, funding for HErZ by DFG and the BMBF was not possible. After many consultations among the ministries and DFG, funding was allocated for the development of HErZ in 2009.

By law, DWD carries out research in meteorology and related disciplines in order to fulfill commitments at the national and international level and supports meteorological research outside of DWD. Research priorities are weather forecasting, climate and environment services, and data acquisition. Research is structured following a three-pillar strategy (Fig. 1). DWD in-house research is predominantly applied. Transitional research is carried out both within DWD and at external institutions, while fundamental research is conducted predominantly outside DWD. Over about a 10-yr time period, theories developed and knowledge gained in fundamental research should be developed into tools and models through transitional research and implemented operationally through applied research and development. HErZ was designed to create and sustain a national academic capability for basic research that provides new developments to advance two of the key objectives of

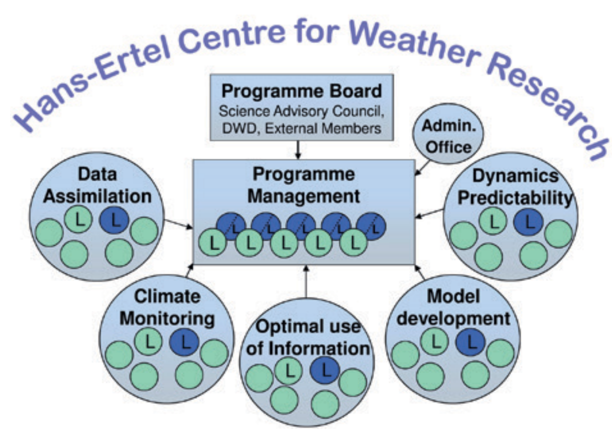

Fig. 2. Structure of the Hans-Ertel Centre for Weather Research. Each of the five branches is led by a tandem of leaders (denoted by L), one employed by the academic institution and the other by the national weather service (DWD). Blue circles indicate DWD employees; green circles indicate university/research institute employees.

both group leaders have the opportunity to establish themselves as leading scientists in HErZ research topics and to achieve the qualification that is prerequisite for applying for professorships in Germany. These structures implant HErZ objectives in German academic research and establish a network of graduates with expertise relevant for DWD.

The HErZ research group leaders and a DWD science manager constitute the program management that is chaired by an elected speaker (Fig. 2). The program is steered and monitored by the program board, whose membership is drawn from the DWD scientific advisory board, the DWD executive board, and additional scientists from academia and from other NMHSs. The board is chaired jointly by the head of the DWD science advisory board and the DWD head of research and development. The DWD further supports HErZ with an administrative unit and oversees all financial matters. HErZ branches can exploit the DWD computing system including test suites of the complete NWP system and access its observations.

The first phase of HErZ was established after an open call for proposals in 2010. Applications were invited for the five priority research areas (branches) defined in the white paper of 2007: atmospheric dynamics and predictability, data assimilation, model development, climate monitoring and diagnostics, and the optimal use of information from weather forecasting and climate monitoring for the benefit of society.

Funding for the second phase was awarded following another open call in 2014 in which the existing groups competed with new proposals from external groups. The successful applicants in phase 2 can apply for an extension to phase 3 in 2018, provided they demonstrate excellence in research and teaching as well as in implementing the sustainability measures discussed below. The funding decisions are based on recommendations from a review panel of international experts from academia and operational research centers.

Sustainability of the Hans-Ertel Centre after the 12-yr core funding period is achieved by four measures:

- university institutes contributing to HErZ are required to create a new permanent position—ideally a professorship—for the HErZ research group by the middle of phase 3, thus anchoring the HErZ research themes at the academic institution;
- the HErZ topics must be established in the meteorological curriculum at the participant universities;

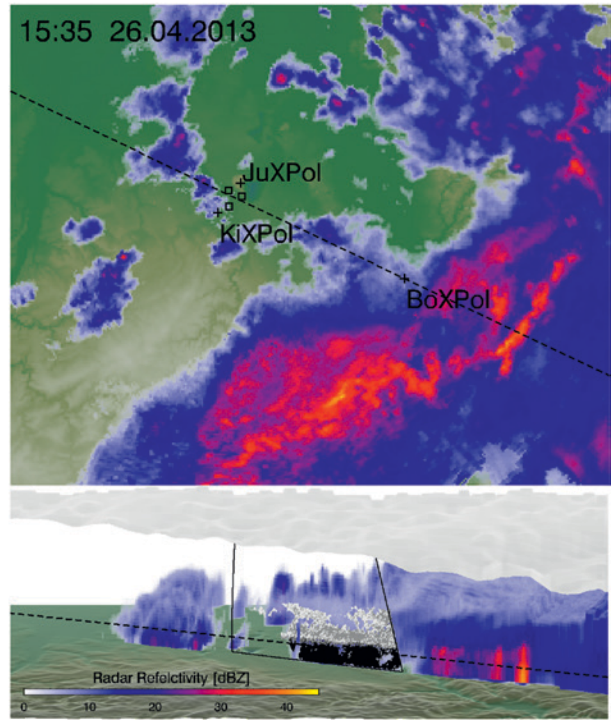

Fig. 3. (top) Horizontal and (bottom) 3D view of vertical cross sections of radar reflectivity along the dashed black line based on the polarimetric X-band radars in Bonn (BoXPol), Jülich (JuXPol), and the mobile radar from the Karlsruhe Institute of Technology (KiXPol). The hydrometeor classification based on Zrnić et al. (2001) adapted for X-band wavelength from one scan is projected into the vertical cross section, showing light rain in black, wet snow in dark gray, dry snow in gray, and dendrites/plates in white. The cloud-top height as provided from the Meteosat Second Generation is also shown in the bottom plot.

- the research groups must acquire third-party funding comparable to the HErZ core funding; and
- the research groups must cooperate with each other and the DWD in order to establish a strong and long-lasting research network.

Funding for the third phase depends on demonstrated success in achieving all the above measures.

HErZ IN PHASE 1: PARTICIPANTS, RESEARCH, AND JOINT ACTIVITIES.

The Hans-Ertel Centre went into operation in 2011 with core funding for five research branches. Their research is summarized briefly in the following paragraphs.

Object-based analysis and seamless prediction was pursued by Bonn University and the Leibniz Center for Tropospheric Research in Leipzig. This branch worked on improved nowcasting via the improved treatment of physical processes in observational nowcasting techniques and the extension of ensemble-based NWP (Milan et al. 2014) by assimilation of nowcasting fields. Central to their effort is a 3D composite derived from radar, satellite, and lightning observations including estimated microphysical variables (Fig. 3). Current efforts concentrate on new retrievals for radar-based quantitative precipitation estimation (QPE; Ryzhkov et al. 2014; Trömel et al. 2014b; Diederich et al. 2015a,b) and microphysical processes (Trömel et al. 2013, 2014a) to improve the composite and enhance its potential use in nowcasting and data assimilation. Convective events are tracked and characterized by descriptors—for example, measures for updraft strength—that provide information on developmental stages and are evaluated for their predictive power (Trömel and Simmer 2012; Senf et al. 2015; Wapler et al. 2015). A climatological exploitation of the event evolutions will elucidate their dynamics and provide an improved understanding and limits of their predictability (Wapler 2013; Wapler and James 2015).

The Ludwig Maximilians University of Munich established ensemble-based convective-scale data assimilation of remote sensing observations as their research focus. This research is challenging given the fast evolution, stochastic nature, and nonlinear dynamics of convection. Data assimilation on this scale demands the assimilation of temporally and spatially high-resolution observations while restoring balance and physical properties and accounting for the inherent analysis and forecast uncertainty through ensemble methods or particle filters. The research group investigates conservation in data assimilation (Janjić et al. 2014) and the use of toy models for testing (Würsch and Craig 2014). Geostationary satellite and weather radar observations are assimilated (Kostka et al. 2014; Lange and Craig 2014) and their contribution to forecast quality is analyzed (Sommer and Weissmann 2014) including the representation of uncertainty in ensemble systems (Harnisch and Keil 2015; Kühnlein et al. 2014). Concrete developments include a fast-forward operator for the assimilation of still underused visible and near-infrared channels of geostationary satellites (Fig. 4; Kostka et al. 2014).

Modeling of convective clouds and stochastic parameterizations were the topics followed by the MPI for Meteorology in Hamburg. Cloud properties, their life cycles, and the interactions with the heterogeneous land surface are investigated with the help of large-eddy simulation (LES) on grid resolutions from 10 to 100 m, which provide a way to advance the understanding of processes currently not observable with the required detail. Characterization of the cloud size distribution (Fig. 5) serves as the organizing principle to derive and parameterize cloud properties. Simulations of organized precipitating shallow convection combined with tracking (Heus and Seifert 2013) led to the identification of self-organization processes on the mesoscale (Seifert and Heus 2013). The results were further used to develop a stochastic model able to capture the variability of the shallow convective cloud ensemble (Sakradzija et al. 2015). The transition from shallow to deeper clouds mainly manifests itself by a change in the size of the largest clouds, which could be linked to cold pools (Schlemmer and Hohenegger 2014) and to the underlying land surface heterogeneity (see Fig. 5 and Rieck et al. 2014). Such links provide simple formulations to be included in new parameterizations.

A high-resolution regional reanalysis project was initiated by the Universities of Bonn and Cologne based on the assimilation of heterogeneous observation networks into NWP models. A COSMO 6.2-km-resolution European reanalysis (COSMO-REA6) has been produced (Fig. 6) with lateral boundary conditions provided by the ECMWF interim reanalysis

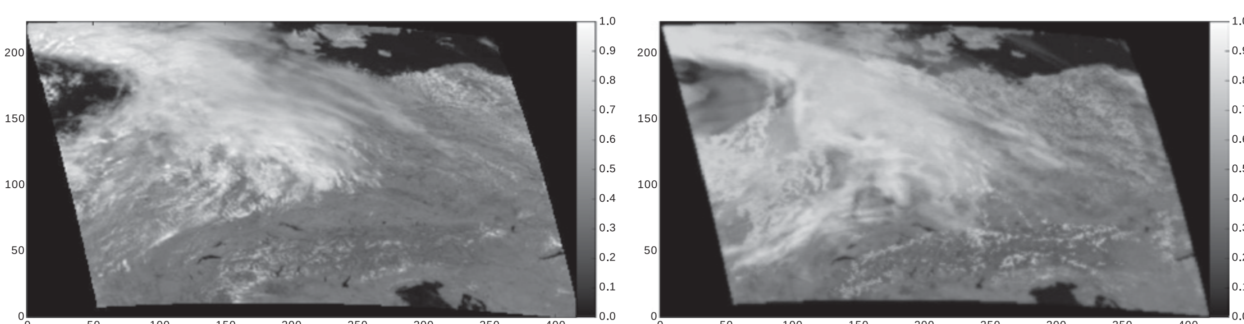

Fig. 4. (left) An observed geostationary satellite image at 800 nm and (right) a synthetic image calculated from a 3-h forecast by the DWD regional NWP model using a new fast forward operator. While the location of clouds is displaced, the model is able to produce realistic cloud structures.

(ERA-Interim; Bollmeyer et al. 2015). COSMO-REA6 serves as the lateral boundary condition for a 2-km resolution reanalysis (COSMO-REA2) covering central Europe. A first comparison of COSMO-REA6 with ERA-Interim (Dee et al. 2011) and a pure dynamical downscaling documents significant added value of the new reanalysis with respect to the representation of extreme events and their spatiotemporal coherence with observations (Bollmeyer et al. 2015). Springer et al. (2014) compare COSMO-RE6 with other simulations for estimating variations in water flux and storage over Europe. The increased level of detail is shown in Fig. 6, which compares the standard Köppen–Geiger maps of Europe after Kottek et al. (2006) (years 1951–2000) with COSMO-REA6 (years 2007–12). As of the end of 2014, 17 yr of COSMO-REA6 and 4 yr of COSMO-REA2 have been processed.

Finally, the Free University of Berlin established an interdisciplinary project on the communication of weather warnings and extreme weather information for the Berlin conurbation. The project involves social science researchers and stakeholders with the goal to provide better information to transport, production, and infrastructure networks that are increasingly vulnerable to weather events. The aim is to improve warning processes and communication and to develop recommendations for appropriate end user–oriented information products with an emphasis on communicating and employing uncertainties. The perception and use of uncertainty in weather warnings is investigated in explorative surveys with emergency managers and interviews with stakeholders (Kox et al. 2015). Figure 7 presents results from a survey on how emergency managers use and judge a DWD online warning tool and its extension to higher spatial detail. Users generally judge the warning tool as a good guidance to assess a weather hazard but are less satisfied with its performance in identifying the location of the hazard. Relationships between severe storms, insured damage, and fire brigade missions are analyzed to identify hotspots of vulnerability. A recently developed manual probabilistic warning product shows that forecasters are able to estimate uncertainty quite reliably at least for moderately severe events. This product is currently being tested with the Berlin fire brigade with respect to its usefulness for operational practice (Pardowitz et al. 2015).

The five branches have begun to develop HErZ into a strong network of meteorological research (Weissmann et al. 2014). Collaborations between the groups include joint research studies, regular internal workshops, several symposia, summer/winter schools, and training courses [e.g., the International Symposium on Data Assimilation (www.isda2014.physik.uni-muenchen.de/index.html), yearly summer schools and training courses on observations and processes related to clouds and precipitation (www.herz-tb1.uni-bonn.de/index.php/summerschool; http://itars.uni-koeln.de/index.php/network-events/summer-school-2014), and a winter school on forecast verification methods]. HErZ plans to organize the "Seventh World Meteorological Organization (WMO) Workshop on Verification Methods" in Germany together with DWD (www.herz-tb4.uni-bonn.de/index.php/component/content/article/22-winterschool).

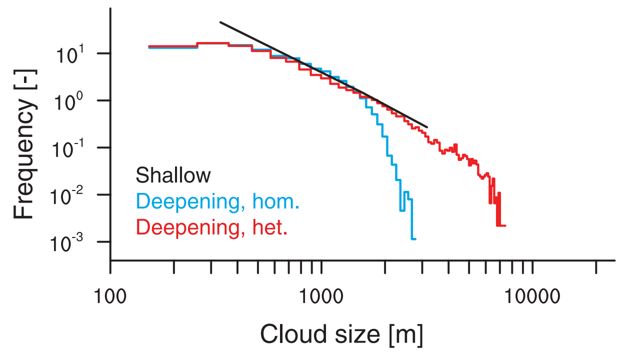

Fig. 5. Cloud size distributions derived from a field of shallow clouds transitioning to deep convection over a homogeneous land surface (blue curve) and over a heterogeneous surface with a heterogeneity size of 12.8 km (red curve). The black curve shows the slope of the cloud size distribution derived from a field of shallow cumulus convection over ocean [taken from Heus and Seifert (2013)]. The flattening of the curves by small clouds is an artifact resulting from insufficient horizontal resolution.

TRANSITION TO PHASE 2. Research in phase 2 continues in the five priority research areas. Priorities for data assimilation and predictability at the University of Munich are to facilitate the assimilation of weather radar and cloud-affected satellite observations in ensemble data assimilation to improve the use of such observations through accounting for model errors and to better understand and represent uncertainty in ensemble forecasts. The model development group focusing on clouds and convection (MPI for Meteorology and University of Hamburg) considers the prominent multiscale forecast challenges associated with the simulation of convection so as to improve the representation of convection across model resolutions. The focus is on the coupling of convection with its environment, including issues

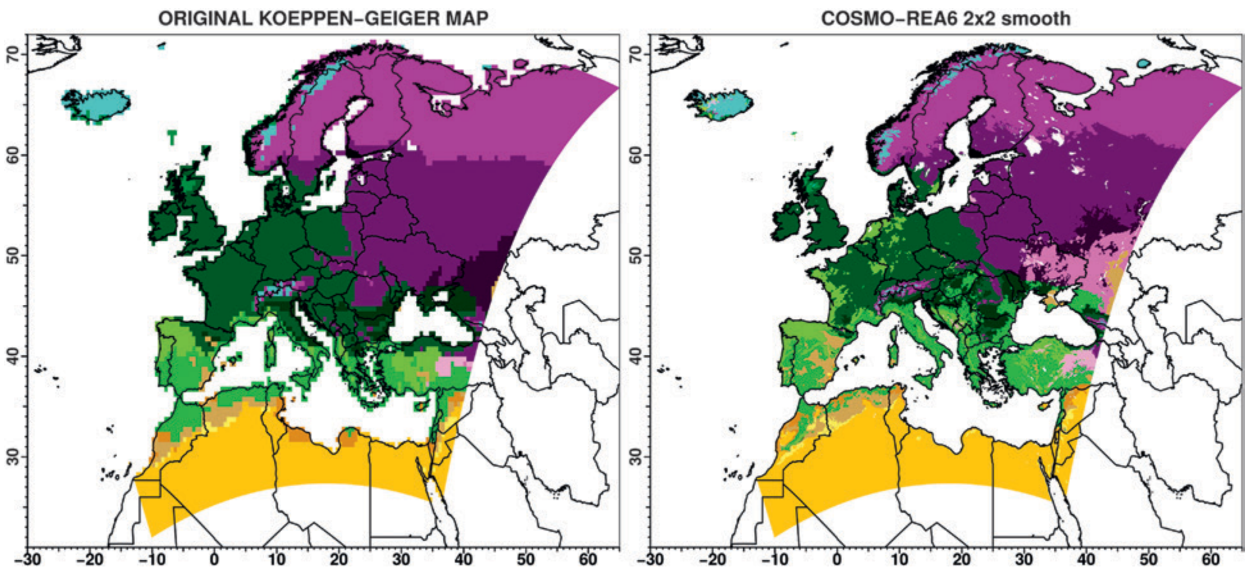

Fig. 6. (left) Standard Köppen–Geiger map of Europe after Kottek et al. (2006) and (right) as obtained from the European reanalysis COSMO-REA6 for the period 2007–12, indicating a finer and slightly different distribution of the standard climate zones based on a high-resolution reanalysis.

related to the organization of convection and its stochastic nature. A new research group from the Goethe University Frankfurt addresses the representation of the atmospheric boundary layer (ABL) in NWP with a specific application to ICON. Stable conditions are to be given special consideration. Stochastic methods will be used to study the stable ABL and to improve turbulence and cloud modeling in ICON. Key objectives for the climate monitoring group (Universities of Bonn and Cologne) are the enhancement of the regional climate monitoring system for Europe, the exploitation of the existing datasets from the first phase, and the provision of scientific guidance for the dissemination and communication of high-resolution reanalyses with a focus on applications such as renewable energy. Research into the optimal use of weather forecasts for society (Freie Universität Berlin, MPI for Human Development) develops effective and efficient ways to use information about the uncertainty of extreme weather information and warnings to mitigate impacts to end users.

IMPACT OF HErZ ON THE TEACHING ENVIRONMENT. HErZ has already had a significant impact on teaching at the participating universities at the bachelor and master levels. At the University of Bonn, the curriculum on nowcasting and short-term prediction has been strengthened, especially in the field of radar polarimetry including hands-on work with weather radar data. Data assimilation and ensemble prediction with practical exercises is in the process of being implemented as a mandatory master's course. The University of Cologne implemented new mandatory courses on ABL meteorology and advanced remote sensing for NWP. The University of Munich installed a new master's course on atmospheric data assimilation. This course will be extended to an NWP course including probabilistic forecasting and hands-on training with DWD operational systems. The MPI for Meteorology has developed a new HErZ curriculum in cooperation with the University of Hamburg to target students across the physical and mathematical sciences; emphasis is put on basic processes related to statistical physics, stochastic processes, atmospheric convection, and convective parameterization. At the Free University of Berlin, a new course on media meteorology was installed. Major advances in teaching are expected in phases 2 and 3 as additional new professorships are being created for HErZ, for example, in social science at the Free University of Berlin on disaster research and public safety and security and in ABL meteorology at the University of Frankfurt. Furthermore, the HErZ groups are expected to work together to make the new courses available at other institutions both within and outside of HErZ.

TRANSITION INTO DWD OPERATIONS. HErZ research will accelerate improvements in the German operational NWP model COSMO, the DWD data assimilation, and nowcasting systems and contribute to the development of the new global-to-regional model ICON. The focus of HErZ is, however, on basic research, and so the short-term transition of the knowledge gained into operations is not prerequisite for the success of the concept. The development of applicable tools and methods takes place predominantly in partnerships between universities, research institutes, and the DWD and is typically funded by external or DWD extramural research grants, while operational implementation is carried out almost entirely by DWD research staff. However, HErZ results are already having an impact on the operations at DWD. An example is an improved formulation of cloud cover (Naumann et al. 2013) that has been proposed by HErZ based on large-eddy simulation results and is currently implemented in the Unified Turbulence Scheme of the COSMO model. HErZ groups contribute to the development of observation operators, for example, for visible and near-infrared satellite channels, for polarimetric radar observations, and for atmospheric motion vector height corrections based on satellite lidar observations (Folger and Weissmann 2014). These all have a strong potential to be included in DWDs operational systems soon. Through HErZ, DWD now contributes to the definition of general requirements for climate monitoring in the European research initiatives Coordinating Earth Observation Data Validation for Re-Analysis for Climate Services (CORE CLIMAX) and Uncertainties in Ensembles of Regional Re-Analyses (UERRA). The HErZ regional reanalysis system for Europe and Germany aims to serve as a new key product to support climate services at DWD on a national as well as European level, with its first commercial application in progress.

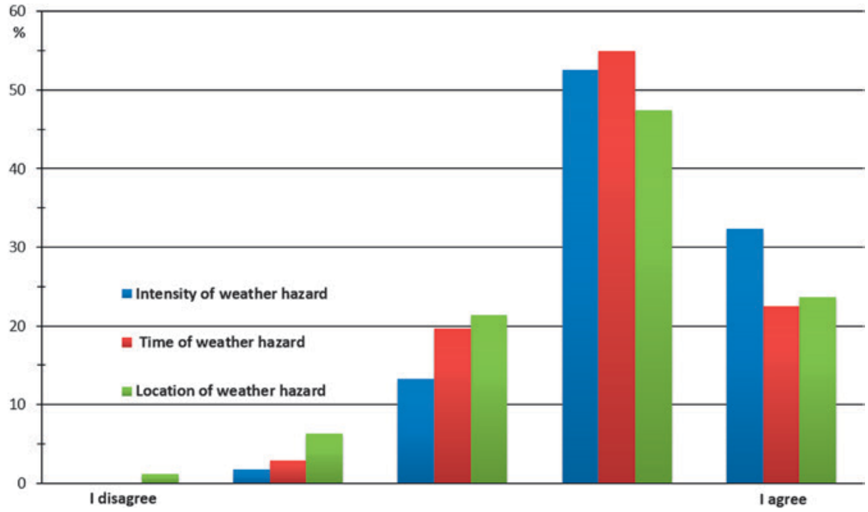

Fig. 7. In an online survey of 174 emergency managers who use an online warning tool, we asked participants for their reaction to the statements that using the tool helps to assess well the "intensity of weather hazards," "the time of weather hazards," and "the location of weather hazards." Bars indicate the relative frequency of answers.

SUMMARY. The Hans-Ertel Centre has already influenced the German research and teaching landscape for weather forecasting and climate monitoring significantly. The privileged interaction of HErZ groups with DWD also facilitates the establishment of links to international and national partner institutions of DWD like the ECMWF and national civil protection agencies. The latter led, for example, to the development and evaluation of a trial probabilistic warning product in cooperation with the Berlin fire service. HErZ has demonstrated that the concept is also very well designed to meet the needs of DWD in fundamental research. Although only about half of the meteorological institutes at German universities could receive core funding via HErZ, the competition has strengthened the position of DWD as a competent partner in atmospheric sciences and laid the basis for a vital research network beyond the HErZ frame.

ACKNOWLEDGMENTS. The success of the Hans-Ertel Centre is only possible through the support received from the German Ministry of Transport and Digital Infrastructure (formerly the Federal Ministry of Transportation, Building and Urban Development). Karl Trauernicht and Dirk Engelbart from that ministry and all members of the DWD science advisory council and the Hans-Ertel Centre Programme Board have provided invaluable assistance in the establishment and steering of HErZ. The implementation of HErZ is greatly assisted by the support of a group of expert international reviewers. The assistance of Insa Thiele-Eich in the revision of this article was extremely valuable. Discussions on the links between academic and operational research in France, Switzerland, and the United Kingdom with Philippe Bougeault, Christof Appenzeller, and Jon Petch are gratefully acknowledged. Finally, we express our deep gratitude to the family of Hans Ertel for their permission to use his name and face for this collaborative research center.

APPENDIX: LIST OF ACRONYMS.

ALADIN	Aire Limitée Adaptation Dynamique Développement International (High-Resolution Numerical Weather Prediction Project)
BMBF	Bundesministerium für Bildung und Forschung (Federal Ministry for Research and Education)
BMVBS	Bundesministerium für Verkehr, Bau und Stadtentwicklung (Federal Ministry for Transportation, Building and Urban Development)
BMVI	Bundesministerium für Verkehr und Digitale Infrastruktur (Federal Ministry for Transportation and Digital Infrastructure)
COSMO	Consortium for Small-Scale Modeling
DFG	Deutsche Forschungsgemeinschaft (German National Research Foundation)
DWD	Deutscher Wetterdienst (German Weather Service)
ETH	Eidgenössische Technische Hochschule (Swiss Federal Institute of Technology)
HErZ	Hans-Ertel-Zentrum für Wetterforschung (Hans-Ertel Centre for Weather Research)
HIRLAM	High Resolution Limited Area Model
ICON	Icosahedral Nonhydrostatic general circulation model
Météo-France	French National Weather Service
MeteoSwiss	Swiss Federal Office of Meteorology and Climatology
Met Office	U.K. National Weather Service
NERC	Natural and Environmental Research Council
NMHS	National Meteorological and Hydrometeorological Service

REFERENCES

Baldauf, M., A. Seifert, J. Förstner, D. Majewski, M. Raschendorfer, and T. Reinhardt, 2011: Operational convective-scale numerical weather prediction with the COSMO model: Description and sensitivities. *Mon. Wea. Rev.*, **139**, 3887–3905, doi:10.1175/MWR-D-10-05013.1.

Bollmeyer, C., and Coauthors, 2015: Towards a high-resolution regional reanalysis for the European CORDEX domain. *Quart. J. Roy. Meteor. Soc.*, **141**, 1–15, doi:10.1002/qj.2486.

Claussen, M., and M. Hantel, 2004: Hans Ertel and potential vorticity—A century of geophysical fluid dynamics. *Meteor. Z.*, **13**, 451, doi:10.1127/0941-2948/2004/0013-0451.

Dee, D. P., and Coauthors, 2011: The ERA-Interim reanalysis: Configuration and performance of the data assimilation system. *Quart. J. Roy. Meteor. Soc.*, **137**, 553–597, doi:10.1002/qj.828.

Diederich, M., A. Ryzhkov, C. Simmer, P. Zhang, and S. Troemel, 2015a: Use of specific attenuation for rainfall measurement at X-band radar wavelengths. Part I: Radar calibration and partial beam blockage estimation. *J. Hydrometeor.*, **16**, 487–502, doi:10.1175/JHM-D-14-0066.1.

——, ——, ——, ——, and ——, 2015b: Use of specific attenuation for rainfall measurement at X-band radar wavelengths. Part II: Rainfall estimates and comparison with rain gauges. *J. Hydrometeor.*, **16**, 503–516, doi:10.1175/JHM-D-14-0067.1.

Ertel, H., 1942: Ein neuer hydrodynamischer Wirbelsatz. *Meteor. Z.*, **59**, 277–281.

Folger, K., and M. Weissmann, 2014: Height correction of atmospheric motion vectors using satellite lidar observations from CALIPSO. *J. Appl. Meteor. Climatol.*, **53**, 1809–1819, doi:10.1175/JAMC-D-13-0337.1.

Fortak, H., 2004: Hans Ertel's life and his scientific work. *Meteor. Z.*, **13**, 453–464, doi:10.1127/0941-2948/2004/0013-0453.

Harnisch, F., and C. Keil, 2015: Initial conditions for convective-scale ensemble forecasting provided by ensemble data assimilation. *Mon. Wea. Rev.*, **143**, 1583–1600, doi:10.1175/MWR-D-14-00209.1.

Hense, A., and V. Wulfmeyer, 2008: The German Priority Program SPP1167 quantitative precipitation forecasting. *Meteor. Z.*, **17**, 703–705, doi:10.1127/0941-2948/2008/0349.

Heus, T., and A. Seifert, 2013: Automated tracking of shallow cumulus clouds in large domain, long duration large eddy simulations. *Geosci. Model Dev.*, **6**, 1261–1273, doi:10.5194/gmd-6-1261-2013.

Janjić, T., D. McLaughlin, S. E. Cohn, and M. Verlaan, 2014: Conservation of mass and preservation of positivity with ensemble-type Kalman filter algorithms. *Mon. Wea. Rev.*, **142**, 755–773, doi:10.1175/MWR-D-13-00056.1.

Kostka, P. M., M. Weissmann, R. Buras, B. Mayer, and O. Stiller, 2014: Observation operator for visible and near-infrared satellite reflectances. *J. Atmos.*

Oceanic Technol., **31**, 1216–1233, doi:10.1175/JTECH-D-13-00116.1.

Kottek, M., J. Grieser, C. Beck, B. Rudolf, and F. Rubel, 2006: World map of the Köppen-Geiger climate classification updated. *Meteor. Z.*, **15**, 259–263, doi:10.1127/0941-2948/2006/0130.

Kox, T., L. Gerhold, and U. Ulbrich, 2015: Perception and use of uncertainty in severe weather warnings by emergency services in Germany. *Atmos. Res.*, **158–159**, 292–301, doi:10.1016/j.atmosres.2014.02.024.

Kühnlein, C., C. Keil, G. C. Craig, and C. Gebhardt, 2014: The impact of downscaled initial condition perturbations on convective-scale ensemble forecasts of precipitation. *Quart. J. Roy. Meteor.*, **140**, 1552–1562, doi:10.1002/qj.2238.

Lange, H., and G. C. Craig, 2014: The impact of data assimilation length scales on analysis and prediction of convective storms. *Mon. Wea. Rev.*, **142**, 3781–3808, doi:10.1175/MWR-D-13-00304.1.

Milan, M., D. Schuettemeyer, T. Bick, and C. Simmer, 2014: A sequential ensemble prediction system at convection-permitting scales. *Meteor. Atmos. Phys.*, **123**, 17–31, doi:10.1007/s00703-013-0291-3.

Naumann, A. K., A. Seifert, and J. P. Mellado, 2013: A refined statistical cloud closure using double-Gaussian probability density functions. *Geosci. Model Dev.*, **6**, 1641–1657, doi:10.5194/gmd-6-1641-2013.

Pardowitz, T., T. Kox, M. Göber, and A. Bütow, 2015: Human estimates of warning uncertainty: Numerical and verbal descriptions. *MAUSAM*, **66**, 625–634.

Rieck, M., C. Hohenegger, and C. C. van Heerwaarden, 2014: The influence of land surface heterogeneities on cloud size development. *Mon. Wea. Rev.*, **142**, 3830–3846, doi:10.1175/MWR-D-13-00354.1.

Ryzhkov, A., M. Diederich, P. Zhang, and C. Simmer, 2014: Potential utilization of specific attenuation for rainfall estimation, mitigation of partial beam blockage, and radar networking. *J. Atmos. Oceanic Technol.*, **31**, 599–619, doi:10.1175/JTECH-D-13-00038.1.

Sakradzija, M., A. Seifert, and T. Heus, 2015: Fluctuations in a quasi-stationary shallow cumulus cloud ensemble. *Nonlinear Processes Geophys.*, **22**, 65–85, doi:10.5194/npg-22-65-2015.

Schlemmer, L., and C. Hohenegger, 2014: The formation of wider and deeper clouds as a result of cold-pool dynamics. *J. Atmos. Sci.*, **71**, 2842–2858, doi:10.1175/JAS-D-13-0170.1.

Seifert, A., and T. Heus, 2013: Large-eddy simulation of organized precipitating trade wind cumulus clouds. *Atmos. Chem. Phys.*, **13**, 5631–5645, doi:10.5194/acp-13-5631-2013.

Senf, F., F. Dietzsch, A. Huehnerbein, and H. Deneke, 2015: Characterization of initiation and growth of selected severe convective storms over Central Europe with MSG-SEVIRI. *J. Appl. Meteor. Climatol.*, **54**, 207–224, doi:10.1175/JAMC-D-14-0144.1.

Sommer, M., and M. Weissmann, 2014: Observation impact in a convective-scale localized ensemble transform Kalman filter. *Quart. J. Roy. Meteor. Soc.*, **140**, 2672–2679, doi:10.1002/qj.2343.

Springer, A., J. Kusche, K. Hartung, C. Ohlwein, and L. Longuevergne, 2014: New estimates of variations in water flux and storage over Europe based on regional (re)analyses and multisensor observations. *J. Hydrometeor.*, **15**, 2397–2417, doi:10.1175/JHM-D-14-0050.1.

Trömel, S., and C. Simmer, 2012: An object-based approach for areal rainfall estimation and validation of atmospheric models. *Meteor. Atmos. Phys.*, **115**, 139–151, doi:10.1007/s00703-011-0173-5.

——, M. Kumjian, A. Ryzhkov, C. Simmer, and M. Diederich, 2013: Backscatter differential phase—Estimation and variability. *J. Appl. Meteor. Climatol.*, **52**, 2529–2548, doi:10.1175/JAMC-D-13-0124.1.

——, A. V. Ryzhkov, P. Zhang, and C. Simmer, 2014a: The microphysical information of backscatter differential phase δ in the melting layer. *J. Appl. Meteor. Climatol.*, **53**, 2344–2359, doi:10.1175/JAMC-D-14-0050.1.

——, M. Ziegert, A. Ryzhkov, C. Chwala, and C. Simmer, 2014b: Using microwave backhaul links to optimize the performance of algorithms for rainfall estimation and attenuation correction. *J. Atmos. Oceanic Technol.*, **31**, 1748–1760, doi:10.1175/JTECH-D-14-00016.1.

Wapler, K., 2013: High-resolution climatology of lightning characteristics within Central Europe. *Meteor. Atmos. Phys.*, **122**, 175–184, doi:10.1007/s00703-013-0285-1.

——, and P. James, 2015: Thunderstorm occurrence and characteristics in Central Europe under different synoptic conditions. *Atmos. Res.*, **158–159**, 231–244, doi:10.1016/j.atmosres.2014.07.011.

——, F. Harnisch, T. Pardowitz, and F. Senf, 2015: Characterisation and predictability of a strong and a weak forcing severe convective event—A multi-data approach. *Meteor. Z.*, **24**, 393–410, doi:10.1127/metz/2015/0625.

Weissmann, M., and Coauthors, 2014: Initial phase of the Hans-Ertel Centre for Weather Research—A virtual centre at the interface of basic and applied weather and climate research. *Meteor. Z.*, **23**, 193–208, doi:10.1127/0941-2948/2014/0558.

Wulfmeyer, V., and Coauthors, 2008: The convective and orographically induced precipitation study: A research and development project of the World

Weather Research Program for improving quantitative precipitation forecasting in low-mountain regions. *Bull. Amer. Meteor. Soc.*, **89**, 1477–1486, doi:10.1175/2008BAMS2367.1.

Würsch, M., and G. C. Craig, 2014: A simple dynamical model of cumulus convection for data assimilation research. *Meteor. Z.*, **23**, 483–490, doi:10.1127/0941-2948/2014/0492.

Zängl, G., D. Reinert, P. Rípodas, and M. Baldauf, 2015: The ICON (ICOsahedral Non-hydrostatic) modelling framework of DWD and MPI-M: Description of the non-hydrostatic dynamical core. *Quart. J. Roy. Meteor. Soc.*, **141**, 563–579, doi:10.1002/qj.2378.

Zrnić, D., A. Ryzhkov, J. Straka, Y. Liu, and J. Vivekanandan, 2001: Testing a procedure for automatic classificiation of hydrometeor types. *J. Atmos. Oceanic Technol.*, **18**, 892–913, doi:10.1175/1520-0426(2001)018<0892:TAPFAC>2.0.CO;2.