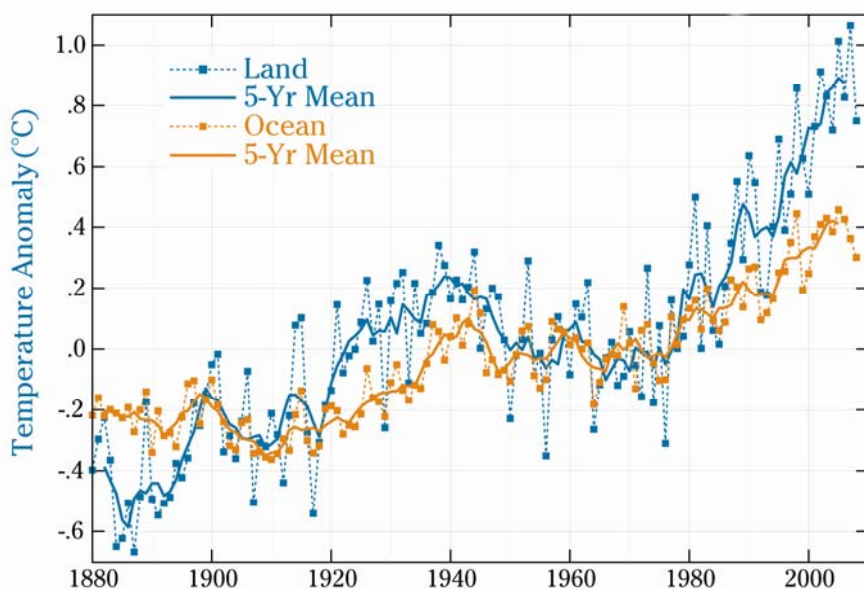


## CLIMATE MONITORING AND RESEARCH

### Vaisala Contributes to Earth's Climate Knowledge



Walter F. Dabberdt  
Nicholas W.S. Demetriades  
Christer Helenelund  
Penny Hickey  
Jarmo Hietanen  
Johanna Lentonen  
Jackie Miller  
Heikki Turtiainen

Annual and five-year (1880-2008) running mean temperature changes for land and ocean (source: NASA Goddard Institute for Space Studies, <http://data.giss.nasa.gov/gistemp/graphs/>).

**PUBLISHED BY**

**Vaisala Oyj  
P.O. Box 26  
FI-00421 Helsinki  
Finland**

**Phone (int.): +358 9 8949 1  
Fax: +358 9 8949 2227**

**Visit our Internet pages at [www.vaisala.com](http://www.vaisala.com)**

**© Vaisala 2009**

**No part of this document may be reproduced in any form or by any means, electronic or mechanical (including photocopying), nor may its contents be communicated to a third party without prior written permission of the copyright holder.**

**This material is subject to copyright protection, with all copyrights retained by Vaisala and its individual partners. All rights reserved. Any logos and/or product names are trademarks of Vaisala or its individual partners. The reproduction, transfer, distribution or storage of information contained in this document in any form without the prior written consent of Vaisala is strictly prohibited. All specifications — technical included — are subject to change without notice.**

---

# Table of Contents

CLIMATE CHALLENGES .....	4
VAISALA'S CLIMATE MEASUREMENT CONTRIBUTIONS .....	6
Climate reference radiosonde.....	6
Global Lightning Dataset.....	8
CO <sub>2</sub> Monitoring .....	9
In Situ Meteorological Monitoring for Climate .....	11
ADDITIONAL INFORMATION .....	13
REFERENCES .....	14

# CLIMATE CHALLENGES

Climate change is a pressing scientific problem and a major worldwide societal and political challenge. Over the past 130 years, the Earth's surface has warmed at an alarming rate – about 0.9°C (1.6°F) when averaged over the global oceans and land masses. As a consequence, sea level is rising, glaciers are retreating and the extent of Arctic sea ice is shrinking (Figure 1). In the face of widespread concern<sup>1</sup>, nations are seeking to respond with effective and affordable mitigation and adaptation strategies.

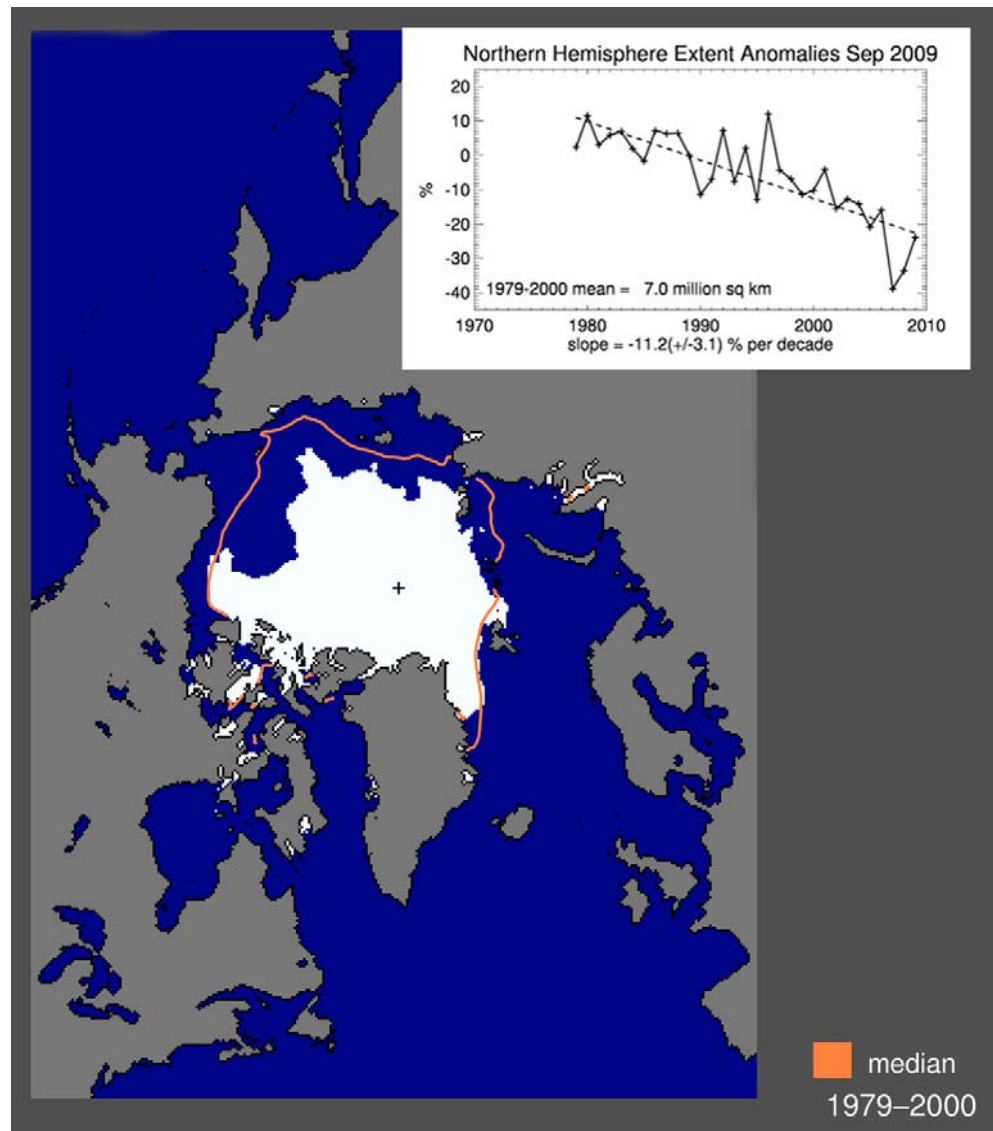
Fundamental to all facets of the climate debate is the need for an extremely accurate, precise and representative record of atmospheric changes – especially temperature, water vapor and precipitation, which need to be measured over multi-decadal timescales and on geographical scales ranging from local to regional and global. On the climate *forcing* side, the record must include the amount and distribution of greenhouse gases (GHGs) such as carbon dioxide (CO<sub>2</sub>), methane (CH<sub>4</sub>), water vapor, chlorofluorocarbons (CFCs) and sulfur hexafluoride (SF<sub>6</sub>), the changes in solar forcing, particulate emissions from volcanic eruptions and wildfires, and carbon fluxes from biomass burning, to cite just a few.

As part of its corporate social responsibility commitment<sup>2</sup>, Vaisala is making important contributions to the climate data challenge by developing new and improved measurement devices and systems. While virtually all of Vaisala's ambient monitoring instruments are used to monitor weather conditions and support research into weather – and hence climate – processes, Vaisala has set out to help meet the special needs of the long-term climate record by developing a climate reference radiosonde, implementing a truly global lightning detection network, building affordable *in situ* CO<sub>2</sub> sensors, an improved precipitation gauge, and automatic weather stations.

---

<sup>1</sup> One recent global poll found nearly three-fourths of those surveyed believe that climate change is a major global problem, but citizens in only four of the 19 countries polled believe their country is doing enough to address climate problems. Source: [www.WorldPublicOpinion.org](http://www.WorldPublicOpinion.org)

<sup>2</sup> [www.vaisala.com/cr](http://www.vaisala.com/cr)



*Figure 1. Arctic sea ice extent for September 12, 2009 (the estimated annual minimum for the year) compared with the median extent for 1979-2000. Also shown is the trend in annual minima for 1979-2009. Source: National Snow and Ice Data Center, Boulder, Colorado.*

# VAISALA'S CLIMATE MEASUREMENT CONTRIBUTIONS

## Climate reference radiosonde

In 2007, World Meteorological Organization's (WMO) Global Climate Observing System (GCOS) laid out the need for a GCOS Global Reference Upper-Air Network, or GRUAN. They concluded (WMO, 2007) that shortcomings in the current upper-air measurement network do not satisfy the accuracy and detail of observations needed to specify climate variability and changes above the Earth's surface. This deficit greatly impacts the ability to accurately assess and predict climate change, and hence has potentially serious consequences in areas of high relevance to society. The overall goal of GRUAN is to establish 30-40 stations that will use reference grade radiosondes in addition to other instrumentation to represent climate around the world (Seidel, 2009). While the current radiosondes support normal weather observation needs rather well, they do not provide sufficiently accurate information for climate and climate-change needs. An improved radiosonde is needed to meet GRUAN's upper-air climate requirements of precision and accuracy.

In January 2009, Vaisala made a corporate commitment to take on this important development challenge by launching an internal program to develop an operational reference-grade radiosonde that could be used in GRUAN and other applications where enhanced radiosonde sensor performance is required. The program is being implemented in close collaboration with the meteorological research community, and the benefits will be shared equally with all countries. Vaisala has also set aside commercial gain from this program in keeping with its Corporate Social Responsibility Program.

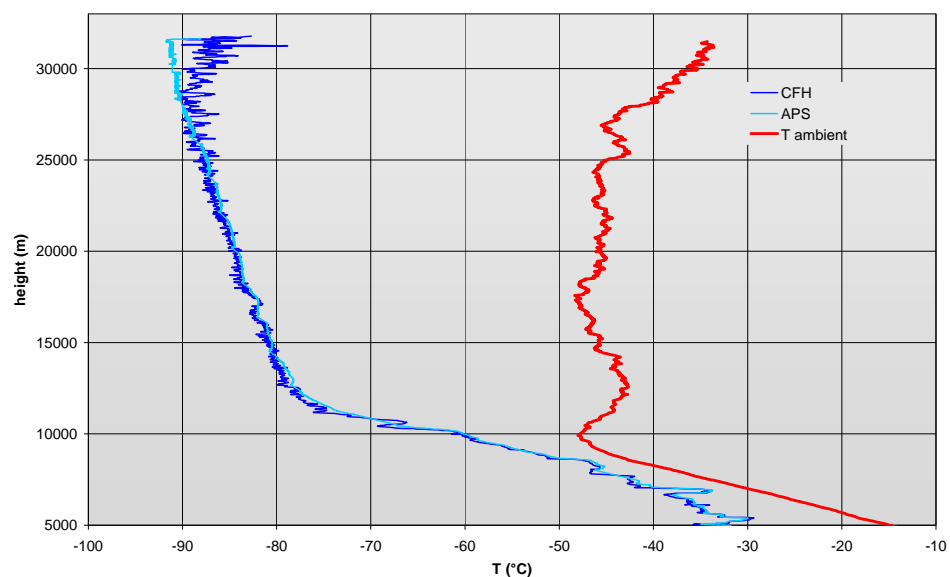
Water vapor is the most abundant and most important greenhouse gas in Earth's atmosphere. However, it is also one of the most difficult parameters to measure with high precision and accuracy, especially in the upper troposphere and stratosphere where

conditions are extremely cold and dry. Therefore, the program is focusing initially on improved upper-air measurements of humidity.

The first version of the operational reference radiosonde is based on the Vaisala Radiosonde RS92 sensors and Vaisala's Advanced Polymer Sensor (APS), a new capacitive sensor capable of measuring extremely low dewpoints. The APS is designed to observe humidity at altitudes to 30 km. It has dewpoint range from  $-30\text{ }^{\circ}\text{C}$  to  $-90\text{ }^{\circ}\text{C}$ , thus supplementing well the conventional RS92 Humicap sensor by providing an independent humidity measurement.

Following internal field trials, external testing began in autumn 2009 in cooperation with several international research partners. The first test results will be reported at the Annual Meeting of the American Meteorological Society, January 2010 (Turtiainen et al., 2010). In parallel with field testing of the APS, the program is also proceeding to develop and test more precise measurements for other atmospheric parameters. Development will continue until the climate science needs (including lower tropospheric requirements) are satisfied for humidity, temperature, pressure and wind soundings.

In addition to developing precise reference instruments, it is imperative to guarantee continuity of standard observation datasets. Accordingly, Vaisala has established a public, web-based database that will provide RS92 radiosonde-related information that affects the interpretation of climatological time series; similar information will be provided for the climate reference radiosonde.



*Figure 2. Upper atmosphere humidity (frost point temperature) measured with Vaisala APS sensor and CFH, a state-of-the-art*

*chilled mirror hygrometer. Ambient temperature is also shown. Sounding was done at Sodankylä, Finland on July 17, 2007. (Balloon borne chilled mirror hygrometers are considered the most accurate instruments for upper atmospheric humidity measurements, but are too expensive and complicated for routine soundings.)*

## Global Lightning Dataset

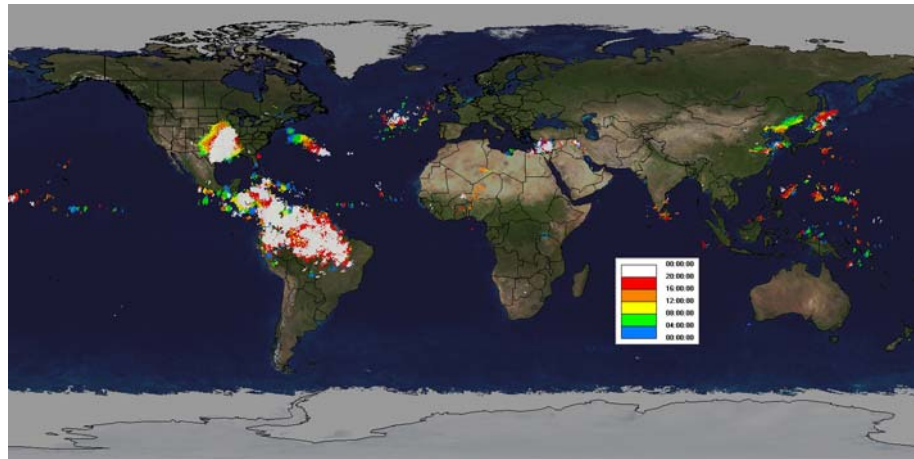
Global lightning data offer great promise for monitoring the impact of climate change on regional-to-global scale convective precipitation and possibly even temperature. Global lightning data also enable climate scientists to study the relationship between regional and larger-scale patterns, thus facilitating the development and evaluation of climate downscaling methodologies. Although a high performance global lightning dataset did not exist until 2009, regional differences in lightning activity have been found during recent warming in the tropics (Petersen and Buechler, 2008). And Pessi and Businger (2009) recently reported on a strong relationship between lightning rates and convective rainfall rate over the North Pacific Ocean, which may be further applied to examine changes in convective precipitation frequency and intensity associated with climate change. Changes in global lightning frequency have also been proposed as a possible proxy for global temperature change (NRC, 1998).

Historically, the creation of a high performance, accurate, and reliable global lightning dataset has presented a substantial challenge to the lightning detection and research communities. Vaisala recently made a major breakthrough in this area through collaboration with Stanford University, which enabled Vaisala to initiate in 2008 the deployment of its Global Lightning Detection Network (GLDN). The GLDN consists of a small number of sensors strategically placed around the world for optimal detection of cloud-to-ground (CG) lightning strokes. These wideband sensors detect CG lightning using magnetic direction finding and time-of-arrival methodologies combined with proprietary lightning recognition algorithms in the VLF (Very Low Frequency) band. Signals captured by these sensors are transmitted to Vaisala's Network Control Center (NCC) in Tucson, Arizona where they are combined with other sensor data to optimize the location estimate of the CG stroke.

On 31 August 2009, Vaisala officially launched the Vaisala Global Lightning Dataset GLD360 at the World Climate Conference 3

(WCC-3) in Geneva. GLD360 is a high performance, accurate, and reliable dataset (see Figure 3) derived from the GLDN. By January 2010, GLD360 will uniformly provide ~70% CG flash detection efficiency across the entire planet with a median stroke location accuracy of 5-10 km and a data latency to users of only one minute. In addition, GLD360 is the only global lightning dataset capable of providing polarity and peak current information for each stroke detected; GLD360 also yields survey-level cloud flash (intra-cloud) detection efficiency of ~5-10%.

GLD360 provides an exciting opportunity for the climate community to continuously monitor relationships between climate change and regional-to-global scale lightning activity and convective precipitation.



*Figure 3. Lightning detected by Vaisala's GLD360 for the 24-hour period ending at 00 UTC 30 October 2009.*

## CO<sub>2</sub> Monitoring

There are several methods for measuring the exchange or flux of CO<sub>2</sub> between terrestrial ecosystems and the atmosphere, the most common being the eddy covariance method. While the eddy-covariance method measures net ecosystem production resulting from photosynthesis and respiration, it cannot provide unique information such as autotrophic and heterotrophic respiration.

Soil respiration is a major component of the terrestrial carbon cycle, constituting up to approximately three-quarters of the total ecosystem respiration (Law et al. 2001). Soil CO<sub>2</sub> measurements are needed to better understand soil gas processes and their eventual impact on climate. Soil respiration has been traditionally studied using the chamber based method; however, the soil CO<sub>2</sub>

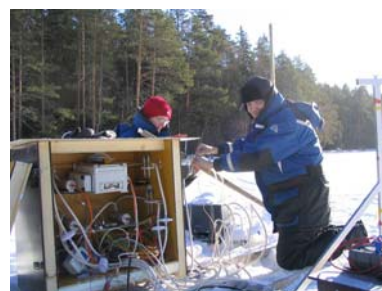
vertical gradient method, where CO<sub>2</sub> probes are buried at different depths in the soil, is becoming increasingly popular (Tang et al. 2003, Pumpanen et al. 2008, Pingintha et al. in press). The gradient method is valuable for clarifying how the CO<sub>2</sub> flux from the soil to the atmosphere varies with season, light conditions, temperature, moisture, and soil properties. It is especially useful in arctic and boreal regions where snow cover lasts for several months, making it difficult for chamber based measurements.

Vaisala manufactures the only CO<sub>2</sub> measuring instruments that can be buried in the soil – the GMT220, GMM220 and GMP343. The probes use the silicon-based, non-dispersive infrared (NDIR) Vaisala CARBOCAP® sensor for the measurement of CO<sub>2</sub>. Its working principle – single-beam dual-wave-length NDIR – is the same method used in expensive high-performance analyzers. However, the traditional rotating wheel is replaced with a tiny, electrically controlled Fabry-Perot Interferometer. A true dual-wavelength measurement can be made in a very simple and practically solid-state structure. The Vaisala CARBOCAP® sensor is accurate and durable and its small size causes minimal disruptions to the soil.



*Figure 4. GMP222 probes in soil CO<sub>2</sub> profile*

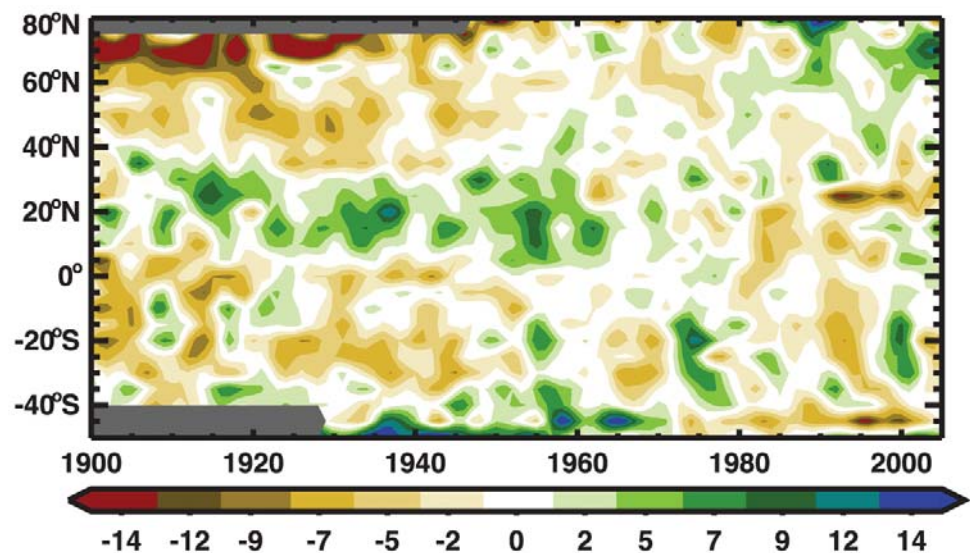
In the study of the global carbon cycle, the role of aquatic systems as a net sink or source of CO<sub>2</sub> is presently under debate (Hari et al. 2008). Measurements of dissolved CO<sub>2</sub> (e.g. p CO<sub>2</sub>) are important for estimating CO<sub>2</sub> transfer across the water-atmosphere interface and calculating metabolic rates of aquatic communities. The most common way to directly measure pCO<sub>2</sub> is the headspace equilibration technique, where the water sample is equilibrated with a headspace gas from which the CO<sub>2</sub> concentration is analyzed with an infrared gas analyzer (McAuliffe, 1971). When the water temperature is measured in connection with CO<sub>2</sub>, pCO<sub>2</sub> can be calculated from Henry's law. The GMP343 and GMT220 series transmitters have been used successfully in this application (Johnson et al. 2006, Hari et al. 2008).



*Figure 5. Equilibrium sampling system including GMP343 CO<sub>2</sub> probes.*

## In Situ Meteorological Monitoring for Climate

While temperature change is perhaps the most obvious indicator of climate change, patterns and intensity of precipitation vary as well. Differences in radiative forcing affect the heating of the earth's surface and consequently also evaporation and sensible heating. In addition, higher temperatures enable air to hold more water vapor. As a result, precipitation patterns have changed in many regions of the globe over the past century (Trenberth et al. 2007). Figure 6 shows zonal anomalies in precipitation observed from 1900 to 2005. In the extreme northern latitudes, upward trends have been detected as indicated by negative anomalies in the early 1900s and positive anomalies in the late 1900s and early 2000s. By contrast, downward trends are seen in the subtropical regions of the northern hemisphere.



*Figure 6. Latitude-time section of zonal average annual anomalies for precipitation (% average departure) over land from 1900-2005 relative to their means from 1961-1990. Gray areas indicate missing data (Trenberth et al. 2007).*

Climate scientists have focused on quantifying regional precipitation patterns because of the difficulties in obtaining accurate and representative precipitation measurements, especially over remote land and oceanic regions as well as during snow and ice events. These challenges underscore the need for quality instrumentation and careful network design. Accurate and reliable datasets with broad geographical coverage will enhance our understanding of the changes in precipitation patterns that accompany climate temperature changes.

The Vaisala All Weather Precipitation Gauge VRG101 and related accessories have been designed for remote automated measurement and to withstand icy, snowy and freezing conditions. Vaisala instrumentation is being used to improve the coverage and quality of precipitation observations for climate monitoring. For example, the Kentucky Mesonet utilizes the VRG101 as the primary precipitation measuring device at each of its 37 mesonet stations (Figure 7). The Vaisala Rain Detector DRD11A is used in conjunction with the VRG101 to support Quality Assurance of the gauge. The Kentucky Mesonet's climate laboratory utilizes precipitation data from the VRG101 in ongoing climate research and modeling. And as the network matures and the dataset is more complete, it will serve as the Kentucky climate record.

Other Vaisala instrumentation is being used in various networks for climate reference monitoring and climate research purposes. The Cooperative Observer Program (COOP) was established over 100 years ago to record climate conditions in the United States and to support agriculture. The National Weather Service (NWS) proposed the Modernization of the COOP to improve weather and climate monitoring through the use of improved instrumentation and increased spatial resolution and temporal frequency of the observations. Vaisala has provided 20 stations for the demonstration phase of this effort. The Vaisala Automatic Weather Station MAWS is a QML-based solution was adapted to meet the NWS specifications and underwent strenuous field trials and qualification tests. For this application, the MAWS station provides temperature measurements using Vaisala Soil/Water Temperature Probe QMT103 sensor.



*Figure 7. Vaisala Rain Gauge installed at the Bowling Green Mesonet station in the Kentucky Mesonet (photo courtesy Kentucky Mesonet).*

The Oklahoma Mesonet is a seminal network of 110 mesonet stations across the state of Oklahoma. Since the inception of the network more than fifteen years ago, Vaisala instrumentation has been used to measure relative humidity and temperature (HMP45C), and pressure (PTB220). The state's official climate record includes monthly summaries from the network. Data from the Oklahoma Mesonet support various climate research studies and applications: Oklahoma climatologists have explored the optimization of climate observing networks (Fiebrich and Crawford 2009), climatic impacts of the winter wheat belt (McPherson et al. 2003), and various other climate-related topics.

## ADDITIONAL INFORMATION

In addition to the instruments and systems described here, Vaisala is also heavily engaged in what may be termed indirect aspects of the climate challenge.

We are pursuing research programs that seek to optimize the way in which wind and solar renewable energy systems can be used to reduce dependencies on energy production with fossil fuels, thereby also reducing emissions of climate-warming greenhouse gases. In the wind energy area, this involves short-range, observationally-based nowcasting of wind ramp events. In the solar energy area, accurate temporal and spatial forecasting of cloud type and amount cover are key emerging challenges being explored.

In depth information on Vaisala's products and services is available at [www.vaisala.com](http://www.vaisala.com); numerous customer applications of Vaisala products are described in previous issues of *Vaisala News*, also available online.

**Acknowledgements.** The authors wish to acknowledge and thank the helpful input and contributions from Vaisala colleagues Annika Ripatti, Keijo Rekorius, and Risto Hölttä.

## REFERENCES

Fiebrich, C.A., and K.C. Crawford, 2009: Automation: A Step toward Improving the Quality of Daily Temperature Data Produced by Climate Observing Networks. *J. Atmos. Oceanic Technol.*, 26, 1246-1260.

Hari, P., J. Pumpanen, J. Huotari, P. Kolari, J. Grace, T. Vesala, A. Ojala. High-frequency measurements of productivity of planktonic algae using rugged nondispersive infrared carbon dioxide probes. *Limnol. Oceanogr.: Methods* 6, 2008, 347–354.

Johnson, M. S.; Lehmann, J.; Couto, E. G.; Novaes Filho, J. P.; Riha, S. J. 2006. DOC and DIC in flowpaths of Amazonian headwater catchments with hydrologically contrasting soils. *Biogeochemistry* 81(1): 45-57.

Law, B. E., Kelliher, F. M., Baldocchi, D. D., Anthoni, P. M., Irvine, J. and co-authors. 2001. Spatial and temporal variation in respiration in young ponderosa pine forests during a summer drought. *Agric. For. Meteorol.* 110, 27–43.

McAuliffe, C. C. 1971. GC determination of solutes by multiple phase equilibration. *Chem. Technol.* 1: 46–51.

McPherson, R. A., D. J. Stensrud, and K. C. Crawford, 2003: The impact of Oklahoma's winter wheat belt on the mesoscale environment. *Mon. Wea. Rev.*, 132, 405-421.

NRC, 1998: *The atmospheric sciences: Entering the twenty-first century (1998)*. Commission on Geosciences, Environment, and Resources of the National Research Council, National Academies Press, Washington, D.C., 364 pp.

Pessi, A., and S. Businger, 2009: Relationships among lightning, precipitation, and hydrometeor characteristics over the North Pacific Ocean. *Journal of Applied Meteorology and Climatology*, in press.

Petersen, W.A., and D. Buechler, 2008: Global tropical lightning trends: Has tropical lightning frequency responded to global

climate change? Preprints, 3<sup>rd</sup> Conference on Meteorological Applications of Lightning Data, January 20-24, New Orleans, Louisiana, American Meteorological Society, 1 pp.

Pingintha, N., Leclerc, M.Y., Beasley, J.P., Zhang, G., Senthong, C. Assessment of the soil CO<sub>2</sub> gradient method for soil CO<sub>2</sub> efflux measurements: comparison of six models in the calculation of the relative gas diffusion coefficient. *Tellus B*. DOI: 10.1111/j.1600-0889.2009.00445.x, In press.

Pumpanen, J., H. Ilvesniemi, L. Kulmala, E. Siivola, H. Laakso, P. Kolari, C. Helenelund, M. Laakso, M. Uusimaa, and P. Hari. Respiration in Boreal Forest Soil as Determined from Carbon Dioxide Concentration Profile. Published online 1 September 2008; doi: 10.2136/sssaj2007.0199. *Soil Sci Soc Am J* 2008 72: 1187-1196.

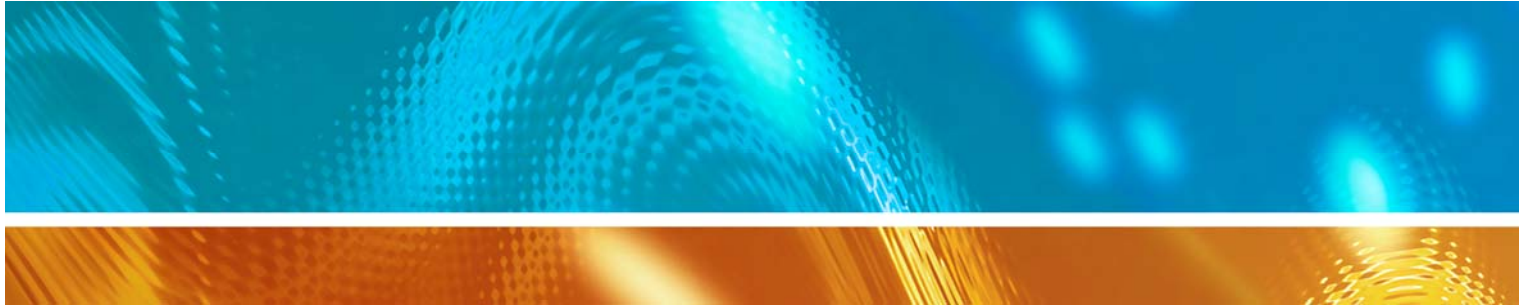
Seidel, D., 2009. Reference Upper-Air Observations for Climate: Rationale, Progress, and Plans, *Bulletin American Meteorological Society*, March 2009.

Tang, J., D.D. Baldocchi, Y. Qi, and L. Xu. 2003. Assessing soil CO<sub>2</sub> efflux using continuous measurements of CO<sub>2</sub> profiles in soils with small solid state sensors. *Agric. For. Meteorol.* 118:207–220.

Trenberth, K.E., P.D. Jones, P. Ambenje, R. Bojariu, D. Easterling, A. Klein Tank, D. Parker, F. Rahimzadeh, J.A. Renwick, M. Rusticucci, B. Soden and P. Zhai, 2007: Observations: Surface and Atmospheric Climate Change. In: *Climate Change 2007: The Physical Science Basis*. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Turtiainen, H, H. Jauhiainen, J. Lentonen, V. P. Viitanen, P. Survo, and W. F. Dabberdt, 2010. Upper atmosphere humidity measurement with the APS sensor—1st progress report on the Vaisala Reference Radiosonde Program. Accepted for presentation in the 15th Symposium on Meteorological Observation and Instrumentation, Atlanta, GA, 17–21 January 2010.

WMO, 2007. GCOS Reference Upper-Air Network (GRUAN): Justification, requirements, siting and instrumentation options, GCOS – 112, (WMO/TD No. 1379), World Meteorological Organization, Geneva, April 2007.



[www.vaisala.com](http://www.vaisala.com)