Flooding in cities like New Orleans (2005) has wreaked havoc, death and destruction.

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A perfect storm?

Climate, weather and demographic changes in the cities

Global population projections indicate that cities will continue to grow rapidly at the expense of rural areas, much in the way that population patterns have already changed since the mid-1980s. Urban growth will be especially pronounced in the developing regions. At the same time, there is compelling evidence that Earth's climate is changing – in part as a consequence of anthropogenic emissions of radiatively important trace gases. Computer model projections indicate these changes will continue for the foreseeable future, pending significant reductions in human-produced emissions.

The recent report of the Intergovernmental Panel on Climate Change reinforces the sense that climate changes will be accompanied by changes in weather, and that there are indications that some climate-induced weather changes may already be happening. In the face of these pronounced changes in population, climate and weather, the importance of short-range weather forecasts and predictions will be even greater in the future.

Especially vulnerable are the low-lying coastal regions where fully ten percent of the world population – 634 million people - lives on just two percent of the world's land with elevation less than 10 m above mean sea level. In the face of these ominous trends, urban forecasts and warnings still depend on observations and data from a surface-based observing system that is synoptic in design and is not well matched to the needs of accurate and precise, high-resolution weather predictions in the cities of today and tomorrow.

This impending "perfect storm" – urban population growth and climate and weather changes – and the implications for public safety must be met in the future by the national meteorological services in partnership with non-governmental organizations, academia and private industry. Together they must implement advanced regional atmospheric observing systems that facilitate markedly improved warnings, forecasts and predictions of weather-related hazards of all types – severe weather, flooding, heat stress, poor air quality, wildfires and disease.

The population challenge

The United Nations Population Division (UNPD, 2002) has prepared estimates and projections of urban and rural populations for major areas, regions and countries of the world for the period 1950-2030. Some say that a tipping point was reached in 2007 when the number of the world's urban dwellers was estimated to have equaled the number of rural dwellers.

According to the UNDP report, the world's urban population reached 2.9 billion in 2000 and is expected to rise to 5 billion by 2030 when the urban proportion will reach 60 per cent.

Virtually all the world's population growth during 2000 – 2030 is expected to be concentrated in urban areas. And almost all of the expected urban population increase will occur in the urban areas of the less developed regions whose population will likely rise from approximately 2 billion in 2000 to just under 4 billion in 2030.

In the more developed regions, the urban population is expected to increase slowly, passing from 0.9 billion in 2000 to 1 billion in 2030. But, urbanization is already very advanced in the more developed regions where an estimated 75 per cent of the population lived in urban areas in 2000. Even so, the concentration of population in the cities of the more developed countries is expected to increase further so that 83 per cent of the inhabitants will be urban dwellers by 2030, as illustrated in Figure 1.

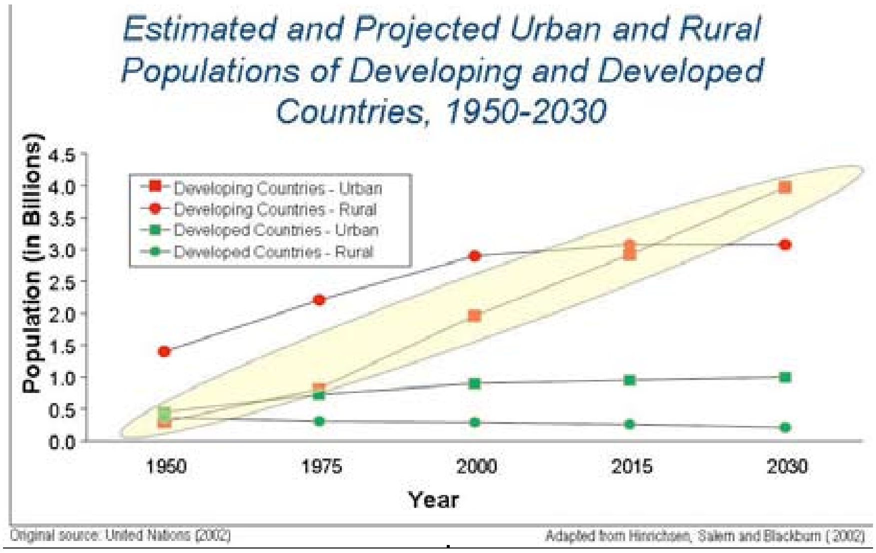

Figure 1. Urban and rural population of the more and less developed regions, 1950-2030 (adapted from: UNPD, 2002, and Hinrichsen, Salem and Blackburn, 2002)

By 2030, the urban percentage in less developed regions is expected to rise substantially to 56 per cent. Compared to 1950, the percentage of the world's total urban population is projected to double by 2030, and it will more than triple in the less developed regions. But perhaps the most profound urban statistic is that of the so-called squatter cities - residential areas in an urban locality inhabited by the very poor who have no access to tenured land of their own, and hence they "squat" on vacant land, either private or public. It is estimated today that one person in six in the world lives in a squatter city!

Earth's changing climate and urban weather

The World Meteorological Organization and the United Nations Environment Programme established in 1988 the Intergovernmental Panel on Climate Change. The role of the IPCC is to assess the scientific, technical and socio-economic information relevant to understanding the scientific basis of risk of human-induced climate change, its potential impacts, and options for adaptation and mitigation. The IPCC's assessments are undertaken by hundreds of global experts who base their analyses on peer reviewed, published scientific and technical literature. The fourth and most recent IPCC assessment report was completed in 2007 (IPCC, 2007a). Table 1 summarizes the IPCC's synthesis of past climate changes, the contributions from human activities, and projected changes in the climate of the 21st century. These changes in Earth's climate portend profound physical and socioeconomic implications.

Low Elevation Coastal Zones (LECZ) are especially vulnerable to severe weather and their vulnerability will be exacerbated in the face of global warming. According to a recent global analysis by McGranahan, Balk and Anderson (2007), the LECZ encompasses two percent of Earth's land area but ten percent of Earth's population and 13 percent of its urban population.

The less developed nations have 14 percent of their population and 21 percent of their urban population living in the LECZ, while for the more developed nations the respective percentages are 10 and 11. Moreover, the very large cities of the world are largely located in the LECZ as nearly two-thirds of urban settlements with populations more than five million are situated in the low-lying coastal zone.

Low-lying coastal populations – urban and rural alike – are vulnerable to flooding from storm surges. But the coastal cities are especially susceptible to flooding. Paved-over and built-up areas increase the amount and intensity of runoff and river flows, putting the cities at greater risk of flooding, while the destruction of wetlands leads to a reduced buffering of tidal floods. These problems are likely to become more acute as the global climate warms and sea levels rise. The 2007 IPCC report estimates that sea level will rise 22 – 34cm in the coming 70 – 80 years in the absence of accelerated melting of the Greenland and West Antarctic ice sheets. It is further estimated that a sea level rise of 38cm would increase by a factor of five the number of people impacted by storm surges.

The urban weather problem is multidimensional with unique and significant impacts on those who live in large urban areas. Conversely, large urban areas can impact local weather, air quality and hydrologic processes in many ways. Urban needs for specialized weather information derive from the diversity of the user groups and population sectors found in urban areas, which include: the general public; air quality management agencies; water supply and sewage facilities; electric power industry; fuel suppliers - natural gas, fuel oil, coal, gasoline; transportation sectors - aviation, marine, and surface; emergency response agencies; public safety agencies; insurance companies and underwriters; health care providers; and recreation facilities.

Urban heat islands can result in urban temperatures that are typically up to 5C greater than those of their rural neighbors, but nighttime differences as large as 12C have been observed. Heat islands result from the combined effects of the thermal and radiative properties of buildings and road surfaces, anthropogenic emissions of sensible heat, and changes in the air-land exchange of heat and water and the corresponding impact on the radiation budget. Changes in surface roughness in urban areas also affect the exchange of heat, mass, and momentum between the surface and the atmosphere, as well as the depth of the urban mixed layer. Hydrological processes are altered to a significant degree as a result of buildings and pavement that affect surface moisture, runoff and streamflow.

Weather impacts urban areas and urban residents in many ways. Heavy rains can cause severe flooding, snow and freezing rain can disrupt transportation systems, severe storms and accompanying lightning and high winds can cause power failures, and so forth. The major direct impact on human mortality results from heat waves, and urban areas are particularly vulnerable because of their high population densities and because urban areas exacerbate conditions that lead to heat stress. Changnon et al. (1996) analyzed the numbers of deaths from various weather conditions in the twentieth century in the U.S. Their analysis clearly showed that heat waves caused more deaths, both on an annual average basis and from single events, than all other weather conditions combined. This was nowhere more evident than in August of 2005 when a prolonged heat wave resulted in more than 30,000 excess deaths in northern and central Europe, including more than 15,000 in France alone.

As mesoscale prediction models increase their spatial resolution, it is increasingly important to properly represent urban influences on the radiation budget, surface moisture, sensible heat exchange processes, and anthropogenic heat and moisture fluxes. This also means that weather observing networks need to be enhanced in order to provide the three-dimensional observations required to properly initialize the models, but also to provide improved information on weather conditions in the cities and to support the observational needs of very short-range nowcasting engines.

Enhanced urban weather observations and the role of testbeds

As important as weather observations and forecasts are today, they will be even more critical in the future as urban areas and populations grow in the face of accompanying changes in global and regional climates. The importance of observing systems that are designed to match the weather requirements of tomorrow's cities is receiving international attention. For example, the Global Earth Observing System of Systems (GEOSS) has included a new task in its GEO 2007 – 2009 work plan: Nowcasting and Forecasting User Applications seeks to "... facilitate the transfer of advanced nowcasting and forecasting capabilities from and to major cities in developed and developing countries [by building] upon the Helsinki Testbed experience to develop user applications related to precision weather forecasts, severe weather warnings, hydrology (including flood control), air-quality forecasting, chemical emergency response, transportation safety, and energy management… The Helsinki Testbed is a Finnish initiative aimed at developing enhanced three-dimensional mesoscale observing networks critical to the advancement of modeling systems and related user applications."

A recent community workshop with international participation considered the requirements of effective mesoscale measurement networks and reached the following conclusion: "existing ... mesoscale measurement networks do not provide observations of the type, frequency, and density that are required to optimize mesoscale predictions and nowcasts. ... To be viable, three-dimensional mesoscale observing networks must serve multiple applications, and the public, private, and academic sectors must all actively participate in their design and implementation as well as in the creation and delivery of value-added products. The [urban] measurement challenge can best be met by an integrated approach that considers all elements of an end-to-end solution: identifying end users and their needs; designing an optimal mix of observations; defining the balance between static and dynamic (targeted or adaptive) sampling strategies; ensuring data standards and data quality, establishing long-term testbeds (i.e. evaluation and demonstration programs); and developing effective implementation strategies." ■

A full version of the article as well as a list of associated references is available at www.vaisala.com/vaisalanews .

Thick smog over Santiago de Chile.

Table 1.
Climate trends, human contribution and projections
(Adapted from: IPCC, 2007b)

Phenomena and Trends	Post-1960 Likelihood that Trend Occurred	Likelihood of Human Contri-bution to Trend	21st-Century Likelihood that Trend Will Occur
Warmer & less frequent cold days & nights over most land areas	Very likely* (* 90 – 99% probability)	Likely+	Virtually certain# (#>99% probability)
Warmer & more frequent hot days & nights over most land areas	Very likely*	Likely+ (nights)	Virtually certain#
Warm spells/heat waves: frequency increases over most land areas	Likely+ (+ 66 – 90% probability)	More likely than not	Very likely*
Heavy precipitation events: Frequency (or % of total from heavy rainfalls) increases over most areas	Likely+	More likely than not	Very likely*
Area affected by droughts increases	Likely+ in many regions since 1970	More likely than not	Likely+
Intense tropical cyclone activity increases	Likely+ in some regions since 1970	More likely than not	Likely+
Increased incidence of extreme high sea level (excludes tsunamis)	Likely+	More likely than not	Likely+