by Ludovic Thobois and Joshua Soderholm

NOWCASTING SEVERE STORMS

Observing clear air close proximity environment of severe storms

Conventional observing systems can be complemented with lidar measurements to better understand and forecast the hazards of severe storms

Severe weather hazards such as storms, hurricanes and thunderstorms, are one of the major threats to both human activity and assets. Human and economic impacts, evaluated at US$485bn in the USA according to a study by the US National Center for Atmospheric Research (NCAR) published in the BAMS Journal in 2011 (BAMS, Volume 92, Issue 6, June 2011), justify the implementation of avoidance and mitigation plans.

Detailed and accurate information on severe weather such as location, intensity and evolution are mandatory to develop efficient and reliable hazard warning systems for alerting the responsible authorities and public. Major improvements have been achieved to better understand and forecast severe weather, thanks to numerical weather models and to the continuous development of meteorological observations, from satellites, radars and more recently lidars.

In the 1970s several projects led by the National Oceanic and Atmospheric Administration (NOAA), the National Severe Storms Laboratory (NSSL) and the National Center for Atmospheric Research (NCAR) focused on the observation and understanding of severe weather phenomena. In 1978 for the NIMROD (National Intensive Meteorological Research on Downburst) project led by the University of Chicago, the downburst and microburst concepts were more specifically identified and developed thanks to the successful deployment of multiDoppler radars, enabling the measurement of the different components of wind.

In the early 1980s the JAWS (Joint Airport Weather Studies) project further developed the methods to detect and recognize the pathway of downbursts and microbursts over airports by building on the observational strategies developed during NIMROD. Thanks to these results, schematic evolution of downbursts and gust fronts was established by Wakimoto in 1982 and the evolution of dry microbursts by Wilson et al. in 1984 (Figure 1). These results demonstrated how new observational sensors can greatly improve in-depth understanding and forecasting of severe storms. These experiments motivated the development of several nationwide C-band or S-band radar networks for measuring precipitation and wind, such as Nexrad WSR-80 in the USA.

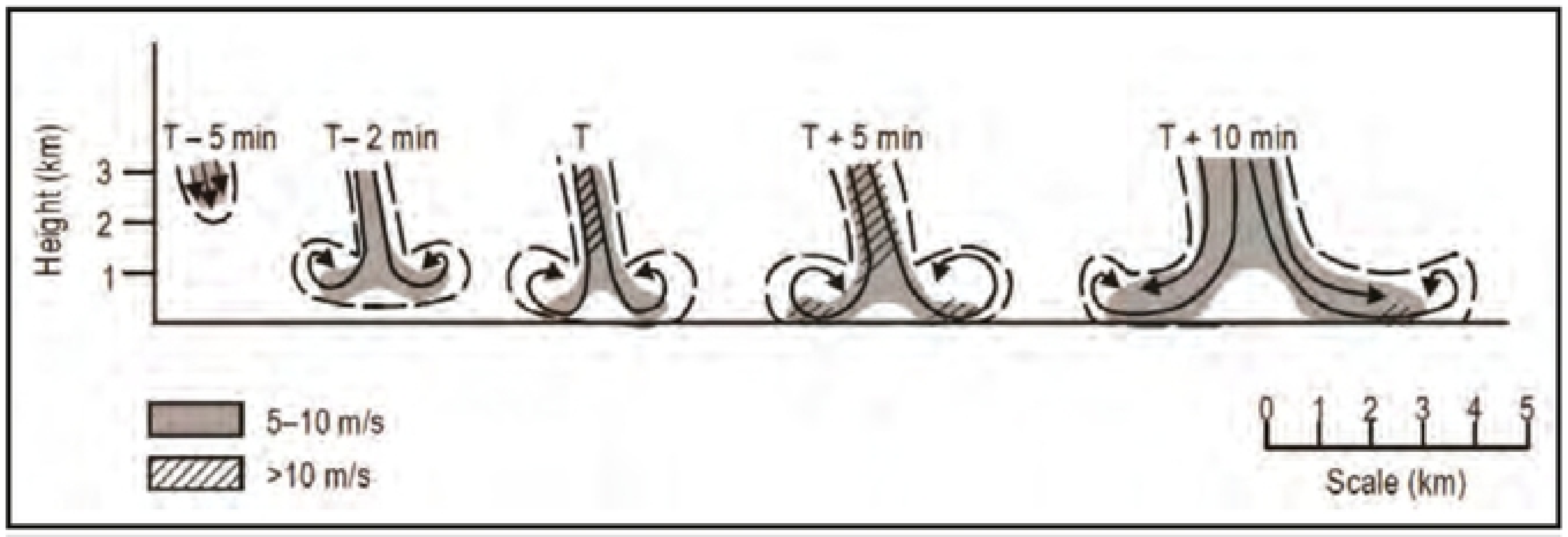

Figure 1: Schematic representation of a dry microburst evolution, Wilson et al. (1984)

Since the 1990s new developments of C-band radars, such as the TDWR (Terminal Doppler Weather Radar) and X-band radars with a higher resolution (200m or less), have been launched to improve severe storm monitoring. Technological advances in X-band radars allowed the Center for Severe Weather Research (CSWR) in Boulder, Colorado, to deploy this technology for the mobile observation of smaller scale severe weather phenomena such as tornadoes.

In the early 2000s the WMO established guidelines for severe weather forecasting and promoted the development of a worldwide network of regionally specialized meteorological centers. The accumulation of observations carried out over multiple decades, especially those from radar and from geostationary orbiting satellites, has greatly improved understanding of severe storms through statistical analyses of frequency, intensity and impact. These long-term observations often reveal the existence of hotspot regions where severe storms are more frequent across many years, or more damaging than other regions. Such analyses suggest that the evolution and characteristics of severe storms are highly dependent on the local environmental interactions and circulations interacting with storms through changes in buoyancy, moisture and shear.

New lidar technology

For the past 20 years, great improvements have been achieved in lidar techniques thanks to the implementation of the optical fiber technology widely used in the mainstream telecommunication industry. It enabled the development of industrial, compact, reliable and accurate atmospheric lidar sensors, such as the Windcube lidars developed by Leosphere. The measurement

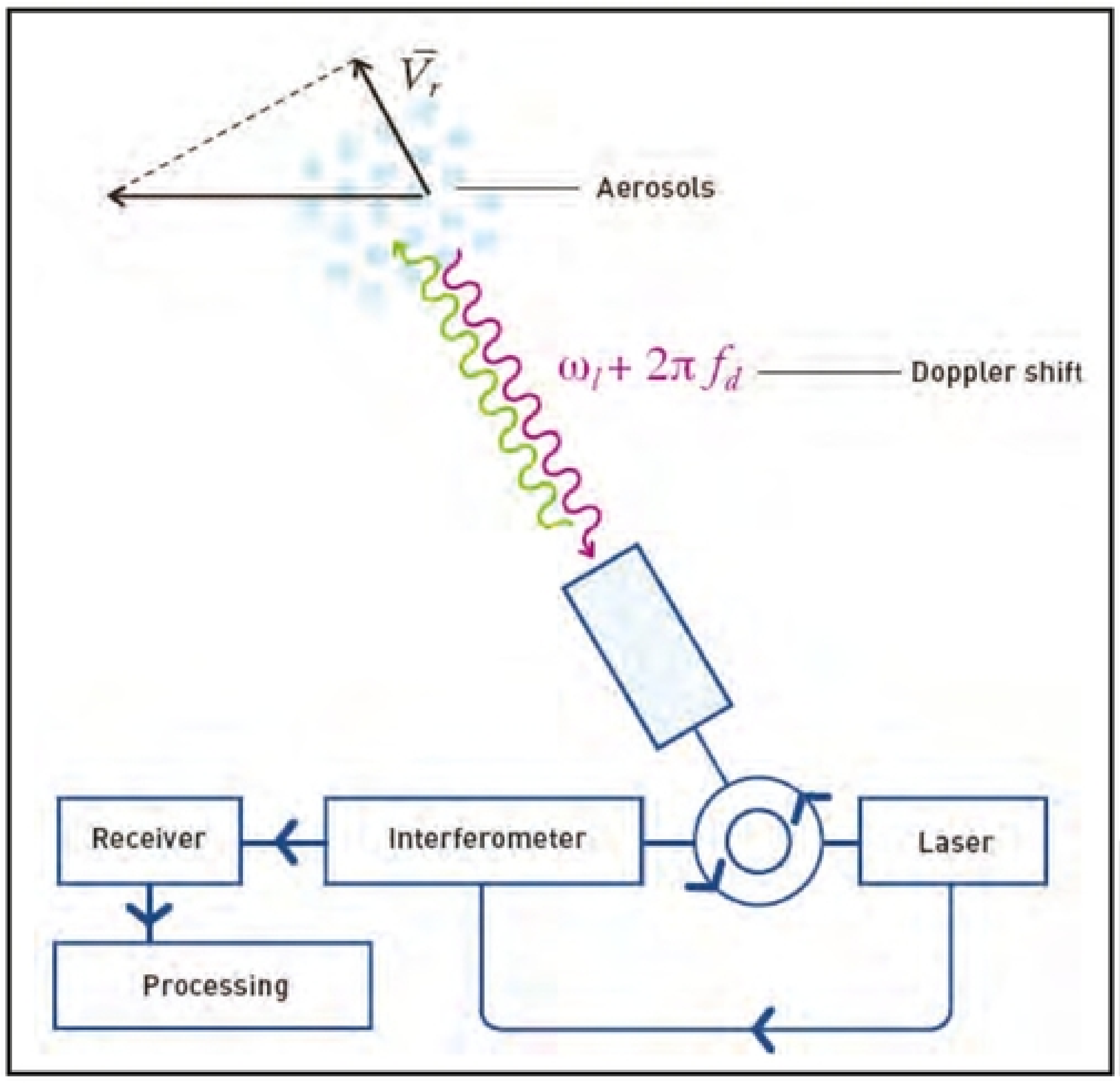

Figure 2: Measurement principle of a coherent Doppler lidar

principle of lidars is similar to radar. The laser source emits pulses of light into the atmosphere (Figure 2). The moving particles backscatter light, shifting its wavelength as a result of the Doppler effect. This shift is proportional to the particles' radial wind speed (projection of the wind vector along the laser line of sight). The backscattered light is detected and then processed to retrieve the radial wind speed as well as other atmospheric phenomena.

A scanning lidar enables observation of the wind flow in a full hemisphere up to 10km in range with adjustable resolution from 25m to 200m and accuracy better than 0.5m/s. Lidar sensors are, for example, being used to better detect local wind hazards, including fine scale low level wind shear around airports under clear air conditions, which conventional Doppler radars cannot resolve effectively. As these sensors suffer strong attenuation under heavy rain, they are considered as complementary to radars, which are less sensitive to clear air processes. The Study and monitoring of severe weather phenomena can benefit from the same lidar sensors to complement already existing radar networks.

Research at Queensland University

The Coastal Convective Interactions Experiment (CCIE) was launched in 2013 in South East Queensland, Australia, by the University of Queensland using a variety of sensors, including a Windcube scanning lidar, to observe the severe storms and the local conditions with which they interact (e.g., meso/microscale frontal boundaries, gust fronts, sea breeze fronts). The CCIE aims to use these observations in combination with climatological analysis to quantify the thunderstorm hotspots for the South East Queensland region and to better understand the meteorological conditions that result in this anomalous spatial behavior of thunderstorms. In Australia, severe thunderstorms account for the greatest insured losses among all natural disasters, so improving forecasts and warnings are a major focus for operational meteorologists. The complexity of local weather circulations and orographic interactions are challenging to understand from the existing observational network and high-resolution modeling system, motivating the development of an extensive observational network for the experiment.

The existing network of C-band/S-band weather radars has provided surveillance of severe storms activity in the region for the past 60 years. A climatological analysis of a continuous 17-year radar dataset reveals a strong link on a meso-gamma scale (2-20km) between localized maxima thunderstorms and sea breeze activity. The complexity of shear and buoyancy interactions of deep convection with sea breezes is difficult to initialize and simulate correctly for individual cases, so an observational approach was developed. To observe the initiation stage of severe storms and monitor the small-scale processes of the interaction between severe storms and sea breezes, a two-season field campaign was coordinated.

Figure 3: Windcube 200S field deployment during CCIE by the University of Queensland

Campaign setup and description

The campaign ran from November 20, 2013, to February 28, 2014. A network of operational weather radars, a research polarimetric dual wavelength radar, radiosondes, and a SODAR (Sonic Ranging and Detection) equipped with a RASS (Radio Acoustic Sounding System) was used. For the first time in Australia, the UQ team mobilized a Windcube scanning Doppler lidar (Figure 3) to collect close proximity observations of

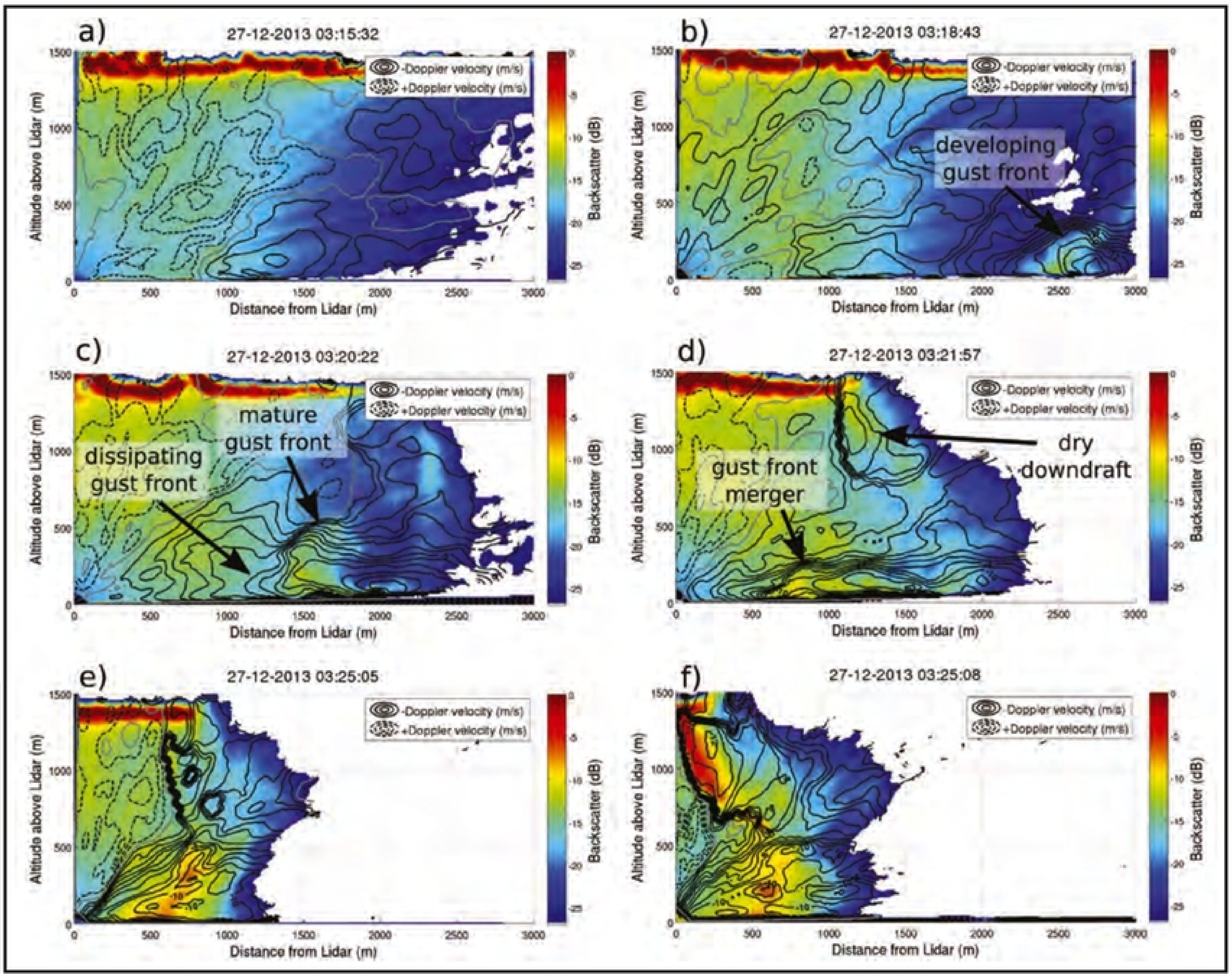

Figure 4: Downburst and gust front evolution at fine spatial and temporal scales measured with the Windcube 200S during CCIE by the University of Queensland

thunderstorms to complement conventional radar datasets. Lidar observations were targeted using high-resolution temporal, spatial and data configurations during clear air processes, which are difficult to resolve with weather radar due to the lack of precipitation and sufficient resolution. This process involved monitoring the close proximity environment around the storm for local circulation (e.g., convective rolls, sea breezes) and studying gust fronts propagating ahead of the storm.

In particular this campaign observed a downburst and gust front evolution at fine spatial and temporal scales using a vertical cross section scan strategy with the Doppler lidar (Figure 4). Wind measurements performed by the lidar revealed the evolution of gust fronts and the properties of a developing downburst. Figure 4a shows the lifted surface air and the detached outflow ahead of the severe storm approaching from the right. The backscatter profile enables the location of the cloud layer at 1.5km (strong backscatter) and the area with precipitation at the right (low backscatter). Complex interactions between a newly formed and decaying gust front leading to a merger were observed over four minutes (Figures 4b, 4c and 4d). Following this merger, a comparatively dry downburst developed behind the maturing gust front, which eventually led to a new gust front once it reached the surface (Figures 4e and 4f). These observations qualitatively agree with the traditional principles for explaining the evolution of a downburst and gust front as established by Wakimoto in the 1980s. Developing this understanding of vertical structure and dynamics using lidar technology provides a basis for understanding subsequent interactions between the sea breeze and gust fronts during the CCIE.

Conclusions and perspectives

Severe weather prediction remains a hot topic for worldwide meteorologists and forecasters, requiring further development of advanced numerical models and observation methods to improve the timeliness and accuracy of forecasts, and the capabilities of operational decisions guidance and warning systems. Over the past decade, new lidar technology has become increasingly widely implemented for meteorological research, and lidar data assimilation has shown (e.g Kawabata et al. 2014) to be a valuable technique for improved forecasting intense mesoscale convective systems (MCS). In particular it provides new observations for severe weather monitoring, which complements those from existing radar networks.

Many recent studies, including the PECAN (Plains Elevated Convection at Night) project in the USA coordinated by NOAA and NASA, the CCIE project in Australia from the University of Queensland, and many others, show that lidars can be used as a powerful tool to observe the environment near severe storms, which plays a major role in their initiation and evolution. These new types of measurements will help modelers to refine numerical weather models and thus their forecasts. They will support researchers and operational forecasters in delivering better warnings of severe storms. The next step is a network of long-range scanning lidars for surveillance over areas of interest such as big cities, small regions or hotspots where severe storms endanger human lives and infrastructure. ▮

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