

## SECTION 2: EXECUTIVE PUBLISHABLE SUMMARY, RELATED TO LAST 18 MONTHS OF PROJECT

Contract n°	EVK2 – 2000 – 00065	Reporting period: last 18 months.	1 APRIL 2004 – 30 SEP 2005 (Last 18 months)
Title	DEVELOPMENT OF A EUROPEAN NETWORK OF STATIONS FOR OBSERVING CLOUD PROFILE		

### Progress with Objectives:

In the last 18 months progress in the primary objectives WP 2-5 was as follows:

- WP2: To operate the three cloud stations, to quality control and archive the data.

Over two years of continuous observations of cloud profiles over three ground stations in the UK, France and NL, together with cloud data over the stations from four operational forecasting models have been quality controlled and placed on the web at [www.cloud-net.org](http://www.cloud-net.org) with quick looks for public access.

- WP3: To develop algorithms for retrieving macroscopic cloud properties, and liquid ice and mixed phase cloud properties from radar and lidar observations.

These algorithms have been developed so the cloud properties such as cloud fraction, liquid and ice water content can be derived; they are then mapped onto the grids of the various operational models (with errors) and placed on the webs with the quick looks.

- WP4: To compare the macroscopic cloud properties, and liquid ice and mixed phase cloud properties inferred from radar and lidar observations with the values held in four European operational forecasting models.

Statistics of model performance in representing clouds by comparing the model output with observations are calculated automatically for all models over periods of months and years. Skill scores are produced so the performances of the models can be objectively determined and any improvements quickly identified.

- WP5: To define the instruments and algorithms for a GCOS cloud observing station.

A specification for a cloud observing stations has been produced involving the optimum mix of instruments which is also economical and could be considered for operational deployment.

### Further Progress with objectives during the six month extension.

Because of the success of CloudNET the scope was extended as follows:

WP2) From the original three observing stations (Chilbolton, UK; Paris, France, Cabauw, NL) to include Lindenberg (Germany) and, after the recommendations of the GEWEX Cloud and Aerosol Profiling Group, to include the ARM stations of the USA Department of Energy located in Oklahoma, Alaska, together with those in the Western Tropical Pacific at Naru and Manus.

WP3) From the four the original operational forecasting models of ECMWF, KNMI (Netherlands, MeteoFrance and the UK Met Office mesoscale model, to include three further models: the Lokal Modell of DWD (Germany), the RCA model of SMHI (Sweden), and the global version of the Met Office Model.

### Scientific achievements:

A consolidated list of 30 breakthroughs is listed below in order of the work package:

*WP1 – Analysis of Existing Cloud Data Sets.* This provides a basis for the work in WP3.

1. Objective evaluation of radar/lidar retrieval of ice particle size and ice water content.
2. First climatology of ice particle size as a function of ice water content and temperature.
3. Characterisation of ice particles using both radar reflectivity and Doppler velocity.

*WP2 – The three cloud stations have been operated 24 hours each day for over two years.*

4. Development of a new technique using the rain return to calibrate the 94GHz cloud radars.
5. Development of an auto-calibration technique for lidars each time there is low level water cloud.
6. Demonstration of absolute cross-calibration for the three cloud radars at the three stations.

*WP3 Development of retrieval algorithms:*

7. Correction of the 30second/60m backscatter profiles and mapping on to the operational model grid.
8. Target classification into different types of cloud (e.g. ice, liquid water) so that the correct algorithm to convert backscatter signals into the variables held in the models can be invoked.
9. Derivation of cloud fraction by mapping observations on to the operational model grid.
10. Establishment of cloud phase (liquid, ice, mixed phase) using lidar depolarisation.

*For targets classified as liquid water we have new techniques for deriving:*

11. Accurate liquid water path (lwp) from dual frequency radiometers using clear sky periods identified with the lidar when lwp is zero to optimise the radiometer calibration factors.
12. Liquid water content profiles by comparing the adiabatic liquid water content profile from observed cloud top and cloud base and then scaling the profile to give the liquid water path observed in 11.
13. Liquid water content from the profile of the radar return and the lidar extinction at cloud base.
14. Drizzle parameters below stratocumulus (Sc) cloud base such as droplet size, concentration, liquid water flux, air velocity – drizzle controls the evolution of Sc clouds which are important to the earth's climate.

*For ice targets, new techniques using the radar reflectivity (Z) to derive ice water content (iwc) using:*

15. Z combined with temperature: capturing changes in particle size and concentration with temperature.
16. Z combined with the Doppler velocity – to derive ice particle densities and size and thus better iwc.
17. A comparison of the iwc derived from different retrieval methods.

*WP4. Comparison of cloud observations with representation in operational models.*

For the first time it has been possible to make an objective comparison of the variables held in the model grid box such as cloud fraction, cloud and ice water content with the observed values. Highlights are:

18. First evaluation of cloud fraction showing, for example, the improved representation of low clouds after 2003 by ECMWF, and the difficulty of the Met Office scheme in filling grid boxes 100% with cloud.
19. Model liquid water content is generally good with the prognostic scheme of the Met office best. All models have difficulty representing supercooled clouds; such clouds have a significant radiative impact.
20. The model iwc is on average rather well represented, at least for clouds below 8km. This is in stark contrast to the worrying order-of-magnitude spread in mean iwc for climate models reported by AMIP.
21. High cloud occurrence. Initially it appears that the model has too much high cloud, but once the data is corrected for the thin clouds not detected by the radar and lidar, the model agreement is satisfactory.
22. The difference in expressing cloud fraction as a volume of the grid box or as a projected area of the grid box has been quantified as has the effect of wind shear on the pdf of iwc within the box.
23. Analysis of model performance classified by weather regime reveals specific failings of the model.
24. Cloud fraction skill scores from 2002 to 2005 quantify model improvements during this time.
25. Confirmation of the improvement of the Meteo-France cloud scheme introduced after the 1999 storms.
26. Testing of proposed Met Office 'PC2' cloud scheme by comparing with cloud statistics from CloudNET
27. Parameterisation of ice effective radius in terms of distance from cloud top instead of temperature has been implemented on the KNMI RACMO model.

*WP5. Specification of a standard cloud observing station.*

28. An economic combination of cloud radar with a simple ceilometer and low cost radiometers.
29. The use low power FM/CW mm wave cloud radars and an X-band pulsed cloud radar.
30. Relaxation of radiometer specification: algorithm 11 can tolerate 5K drifts in brightness temperatures.

#### **Socio-economic relevance and policy implications:**

As a result Europe now has the infrastructure to:

- a) Observe, on a continuous basis, profiles of cloud properties at four ground stations in Europe and four outside Europe, which are then converted into the cloud variables (with defined errors) used in climate and weather forecasting models and archived together with the output of seven operational forecast models for the grid box over the observing station in NetCDF format on a publicly accessible web site.
- b) Compare the cloud variables derived from observations with the model representation and provide statistics of model performance including skill scores, updated monthly, of the ability of the models to represent clouds. These statistics available on the web site enable new cloud parameterisations implemented on the models to be rapidly evaluated. Climate models essentially use the same cloud parameterisations.
- c) Manufacture at an economic cost cloud observing stations which could be deployed operationally.

At the final CloudNET symposium in Germany (Oct 2005) representatives of National Weather Service and Climate Prediction Centres were present (ECMWF, Met Office, MeteoFrance, DWD, SMHI, KNMI) and expressed their enthusiasm for the model evaluations produced by CloudNET and their wish that, now the investment in infrastructure had been made, the CloudNET project continue so that it could provide evaluations of the performance of future versions of climate and weather forecasting models.

#### **Keywords:**

Cloud radar and lidar. Cloud properties. Forecast and climate models. Flooding and the hydrological cycle. Future climate change.

**PUBLICATIONS:** 30 Peer Reviewed Articles and 34 non-refereed articles.

*Peer Reviewed Articles*

<b>Authors</b>	<b>Date</b>	<b>Title</b>	<b>Journal<sup>1</sup></b>	<b>Reference</b>
Delanoe J, Protat A, Bouniol D, Testud J., Heymsfield A, Bansemer A, and Brown P	2006	An ice cloud climatology over Europe from two years of continuous cloud radar observations.	JClimate	Submitted
Delanoe J, Protat A, Bouniol D, Testud J., Heymsfield A, Bansemer A, and Brown P	2006	Evaluation of operational weather forecast models using two years of cloud radar observations;	JAM	Submitted
Protat, A., A. Armstrong, M. Haeffelin, Y. Morille, J. Pelon, J. Delanoë, and D. Bouniol	2006	The impact of conditional sampling and instrumental limitations on the statistics of cloud properties derived from cloud radar and lidar at SIRTA	GRL	Accepted
Morille Y., M. Haeffelin, P. Drobinski, J. Pelon,	2006	STRAT : An algorithm to retrieve the STRucture of the ATmosphere from single channel lidar data	JAOT	Submitted
Chiriaco M., R. Vautard, H. Chepfer, M. Haeffelin, J. Dudhia, Y. Wanherdrick, Y. Morille et A. Protat	2006	The Ability of MM5 to Simulate Ice Clouds : Systematic Comparison between Simulated and Measured Fluxes and Lidar/Radar Profiles at SIRTA Atmospheric Observatory	MWR	In press
Haeffelin, M., L. Barthès, O. Bock, C. Boitel, S. Bony, D. Bouniol, H. Chepfer, M. Chiriaco, J. Cuesta, J. Delanoë, P. Drobinski, J-L. Dufresne, C. Flamant, M. Grall, A. Hodzic, F. Hourdin, F. Lapouge, Y. Lemaître, A. Mathieu, Y. Morille, C. Naud, V. Noël, B. O'Hirok, J. Pelon, C. Pietras, A. Protat, B. Romand, G. Scialom, R. Vautard,	2005	SIRTA, a ground-based atmospheric observatory for cloud and aerosol research	AnnGeo	23, pp 253-275.
Russchenberg, H., Bosveld, F., Swart, D., ten Brink, H., de Leeuw, G., Uijlenhoet, R., Arbesser-Rastburg, B., van der Martel, H., Ligthart, L., Boers, R., and Apituley, A.	2005	Ground-Based Atmospheric Remote Sensing in the Netherlands: European Outlook	IEICE Transactions on Communications	<b>E88-B</b> , No.6, 2252-2258
Delanoe J, Protat A, Bouniol D, Testud J., Heymsfield A, Bansemer A, and Brown P	2006	RadOn; a new method for retrieval of the dynamical, microphysical and radiative properties of ice clouds from Doppler cloud radar observations	JAOT	Submitted

Protat A, Delanoe J, Bouniol D, , Heymsfield A, Banesemar A, Brown P, and Forbes R	2005	Evaluation of ice water content retrievals from cloud radar reflectivity and temperature using al large airborne in-situ microphysical data base.	JGR	Submitted
Tinel C., J. Testud, J. Pelon, R J Hogan, A. Protat, J. Delanoe and D. Bouniol.	2005	The retrieval of ice cloud properties from cloud radar and lidar synergy.	JAM	44, 860-875.
Delanoe J, Protat A, Testud J., Heymsfield A, Banesemar A, Brown P, and Forbes R..	2005	Statistical properties of the normalized ice particle size distribution	JGR	110, D 10201.
Delanoe J, Protat A, Testud J., Heymsfield A, Banesemar A, Brown P, and Forbes R.	2005	Cloud dynamical, microphysical and radiative properties from Doppler cloud radar measurements	JAM, JGR	In preparation.
Hogan R. J., Donovan D. P., Tinel D., Brooks M. A., Illingworth A. J. and J. P. V. Poiras Baptista.	2006	Independent evaluation of the ability of spaceborne radar and lidar to retrieve the microphysical and radiative properties of ice clouds.	JAOT	23, 211-227.
Hogan R J, Mittermaier MP and A J Illingworth	2006	The retrieval of ice water content from radar reflectivity factor and temperature and its use in evaluating a mesoscale model	JAM	45, 301 -317
Gaussiat N., Hogan R. J. and A. J. Illingworth.	2005	Stratocumulus liquid water content from dual wavelength radar.	JAOT	22, 1207-1218
Brooks M. E., Hogan R. J. and A. J. Illingworth	2005	Parameterizing the difference in cloud fraction defined by area and by volume as observed with radar and lidar.	JAS	62, 2248-2260.
O'Connor E. J., Illingworth A. J. and R. J. Hogan	2005	Retrieving stratocumulus drizzle parameters using Doppler radar and lidar	JAM	44, 14-27.
Schutgens N. and D. Donovan	2004	Retrieval of atmospheric reflectivity profiles in the case of long radar pulses.	Atmosph Research	72, 187-196
van Zadelhoff G. J., D. P. Donovan, H Klein Baltink, and R Boers.	2004	Comparing ice-cloud microphysical properties using CloudNET and Atmospheric Measurement Program data.	JGR	109, D2414, doi 10.1029/2004JD004967
Protat A, Pelon J, Testud J, Grand N, Delville P, Labotie P, Vinson J-P, Bouniol D, Bruneau D, Chepfer H, Delanoe J, Haeffelin M, Noel V, Tinel C	2004	Combinaison d'un radar nuage et d'un lidar pour l'etude des nuages faiblement precipitants.	La Meteorologie	47, 23-33
Donovan D. P.	2004	Ice-Cloud effective particle size parameterization based on combined lidar, radar reflectivity, and mean Doppler velocity measurements	JGR	<b>108</b> , No. 18, 10.1029/2003JD003469

O'Connor E. J., Illingworth A. J. and R. J. Hogan	2004	A technique for auto-calibration of cloud lidar	JAOT	21, 777-786
Hogan R. J., Flentje H., Francis P. N., Illingworth A. J., Quante M. and J. Pelon.	2003	Characteristics of mixed phase clouds. Part1: Lidar, radar and aircraft observations from CLARE '98	QJRMS	129, 2089-2116
Hogan, R J, A J Illingworth, J P V Poiras Baptista and E J O'Connor	2003	Characteristics of supercooled clouds: Part II A climatology from ground-based lidar	QJRMS	129, 2117-2134
Hogan, R J, and A J Illingworth	2003	Parameterizing ice cloud inhomogeneity and the overlap of inhomogeneities using cloud radar data	JAS	60, 756-767
Gaussiat N., Sauvageot H. and A. J. Illingworth	2003	Cloud liquid water and ice content retrieval by multi-wavelength radar	JAOT	20,1264-1275
Baedi, R.; Boers,R.; Russchenberg, H.W.J	2003	Detection of Boundary Layer Water Clouds by Spaceborne Cloud Radar	JAOT	19, 1915–1927
Hogan R. J, Bouniol D. H., Ladd D. N., O'Connor E. J. and A. J. Illingworth	2003	Absolute Calibration of 94-GHz radars using rain	JAOT	20, 572-580
Donovan D. P.	2002	First ice cloud effective particle size parameterization based on combined lidar and radar data	GRL	29, No. 1, 10.1029/2001GL 013731

*Non refereed literature:*

Authors / Editors	Date	Title	Event	Reference	Type <sup>1</sup>
Krasnov,, O.A. and H. W. J. Russchenberg,	2005	A synergetic radar-lidar technique for the LWC retrieval in water clouds: Description and application to the Cloudnet data,	32 <sup>nd</sup> AMS Conference on Radar Meteorology, Albuquerque		Paper
Spek L., , D. Moisseev, H. Russchenberg, C. Unal, and V. Chandrasekar	2005	Retrieval of microphysical properties of snow using spectral dual polarization analysis,	32 <sup>nd</sup> AMS Conference on Radar Meteorology, Albuquerque		Paper

<sup>1</sup> QJRMS: Quarterly Journal of the Royal Meteorological Society; JAM: Journal of Applied Meteorology; JAS: Journal of the Atmospheric Sciences; JAOT: Journal of Atmospheric and Oceanic Technology; JGR: Journal of Geophysical Research; GRL: Geophysical Research Letters.

<sup>1</sup> Type: Abstract, Newsletter, Oral Presentation, Paper, Poster, Proceedings, Report, Thesis

Unal C.M.H. , H. W. J. Russchenberg and D. N. Moisseev,	2005	Simultaneous wind velocity estimation and dual-polarization measurements of precipitation and clouds by an S-band profiler	32nd AMS Conference on Radar Meteorology, Albuquerque		Paper
May G., H. W. J. Russchenberg and O. A. Krasnov	2005	Radar-lidar synergy for space-based retrieval of water cloud parameters	32 <sup>nd</sup> AMS Conference on Radar Meteorology, Albuquerque		Paper
Illingworth A.J. et al	2005	Cloudnet, Evaluating clouds in six operational forecast models using cloud radar and lidar observations.	32nd AMS Conference on Radar Meteorology, Albuquerque		Paper
Russchenberg H.W.J.	2005	Ground based atmospheric remote sensing in the Netherlands: A European outlook.	Scientific Assembly		Paper
Haefelin M et al.	2005	Evaluation of mid-latitude ice cloud properties using MM5 mesoscale model and remote-sensing measurements at SIRTAs atmospheric observatory	Scientific Assembly, IAMAS, Beijing		Paper
Illingworth et al	2005	Comparison of observed cloud properties at three ground bases sites with their representation in operational models: The EU CloudNET project.	Scientific Assembly, IAMAS 2005, Beijing		Paper
Bouniol D., Illingworth A. J. and R. J. Hogan.	2004	Deriving turbulent kinetic energy dissipation rate within clouds using ground based 94GHz radar.	3 <sup>rd</sup> European Radar Conference, Sweden.		Paper
Illingworth et al.	2004	Observing cloud properties with ground-based mm-wavelength radar.	3 <sup>rd</sup> European Radar Conference, Sweden.		Paper
van Zadelhoff G. J. and D. P. Donovan.	2004	Comparing ice-cloud microphysical properties using CloudNET and ARM data.	14 <sup>th</sup> ICCP conf, Bologna.		Paper
Wilson D. R., Kerr-Munslow A. M. and A. C. Bushell.	2004	The behaviour of different cloud process parametrizations in a large-scale model	14 <sup>th</sup> ICCP conf, Bologna.		Paper

Protat A., Bouniol D. and Martial Haeffelin.	2004	Evaluation of vertical air velocity and its distribution in four operational forecast models using continuous Doppler cloud radar measurements.	14 <sup>th</sup> ICCP conf, Bologna.		paper
Bouniol D., Protat A., M. Haeffelin.	2004	A systematic retrieval of ice cloud microphysical and radiative properties using a synergetic radar/lidar algorithm.	14 <sup>th</sup> ICCP conf, Bologna.		Paper
O'Connor E., Hogan R. J. and A. J. Illingworth.	2004	Characteristic of drizzling and non-drizzling stratocumulus as revealed by vertical pointing cloud radar and lidar.	14 <sup>th</sup> ICCP conf, Bologna.		Paper
Gaussiat N., Hogan R. J. and A. J. Illingworth.	2004	Cloud water content and cloud particle characteristics revealed by dual wavelength cloud radar observations.	14 <sup>th</sup> ICCP conf, Bologna.		Paper
Illingworth et al.	2004	Comparison of observed cloud properties at three ground sites with their representation in operational models: The EU CloudNET project.	14 <sup>th</sup> ICCP conf, Bologna.		Paper
Brook M. E. Hogan R. J. and A. J. Illingworth.	2004	A long comparison of cloud properties observed by vertically pointing radar and lidar with their representation in operational NWP models	14 <sup>th</sup> ICCP conf, Bologna.		paper
Agnew J. L. and Hewison T. L.	2004	Comparison of Water Vapour Profiles Measured using a Raman Lidar and a Microwave radiometer at Chilbolton observatory.	22 <sup>nd</sup> ILRC conference, 12-16 July 2004		paper.
Gaussiat N. and A. J. Illingworth	2003	Investigating the density of ice particles using dual-wavelength Doppler data.	31 <sup>st</sup> Int Conf on Radar Meteorology, Seattle.	AMS 2003 Radar Conf Proceedings, pp. 137-139	Paper
Illingworth A. J. and D. H. Bouniol.	2003	Improved radar rainfall estimates: What index use in the gamma function for the drop spectrum.	31 <sup>st</sup> Int Conf on Radar Meteorology, Seattle.	AMS 2003 Radar Conf Proceedings, pp. 11-13	Paper

Bouniol D., Illingworth A. J. and R. J. Hogan.	2003	Deriving turbulent kinetic energy dissipation rate within clouds using ground based 94 GHz radar.	31 <sup>st</sup> Int Conf on Radar Meteorology, Seattle.	AMS 2003 Radar Conf Proceedings, pp. 193-195	Paper
D.P. Donovan	2003	Effective ice cloud Size distribution parameterization using combined lidar, radar reflectivity and Doppler velocity measurements	EGS-AGU-EUG Joint assembly, Nice, France		Oral
D.P. Donovan	2002	Effective particle sizes in Cirrus derived from combined lidar, radar reflectivity and Doppler velocity measurements.	European Conference on Radar Meteorology, 18 - 22 November 2002, Delft, The Netherlands.	ERAD 2002 Proceedings, Vol. 1 - pp. 173 – 178	Paper
Krasnov O and Russchenberg H	2002	An enhanced algorithm for the retrieval of liquid water cloud properties from simultaneous radar and lidar measurements. Part I: The basic analysis of in-situ drop spectra.	European Conference on Radar Meteorology, 18 - 22 November 2002, Delft, The Netherlands.	ERAD 2002 Proceedings, Vol. 1 - pp. 173 – 178	Paper
Krasnov O. and H. Russchenberg	2002	An enhanced algorithm for the retrieval of liquid water cloud properties from simultaneous radar and lidar measurements. Part II : Validation using ground based radar, lidar and microwave radiometer data	European Conference on Radar Meteorology, 18 - 22 November 2002, Delft, The Netherlands.	ERAD 2002 Proceedings, Vol. 1 - pp. 179 – 183	Paper
Heijnen S. H. Klein-Baltink H., Russchenberg W. J. and W. F. van der Zwan	2002	Polarimetric cloud studies at 3.3.GHz.	European Conference on Radar Meteorology, 18 - 22 November 2002, Delft, The Netherlands.	ERAD 2002 Proceedings, Vol. 1 - pp. 117 – 121	paper
Protat A, Tinel C. and J. Testud	2002	Dynamic properties of clouds and dynamic/microphysical interactions from 94GHz radar and lidar.	European Conference on Radar Meteorology, 18 - 22 November 2002, Delft, The Netherlands.	ERAD 2002 Proceedings, Vol. 1 - pp. 155 – 158	paper
Tinel C., Testud J., Protat A., and J. Pelon	2002	Microphysical and radiative properties of ice clouds using a cloud radar-lidar algorithm	European Conference on Radar Meteorology, 18 - 22 November 2002, Delft, The Netherlands.	ERAD 2002 Proceedings, Vol. 1 - pp. 184 – 187	paper

Illingworth A. J., Hogan R. J., Brooks M. E., and E. J O'Connor.	2002	The use of cloud radar and lidar data for validating clouds in operational forecasting models.	2nd Workshop on Spaceborne Cloud Profiling Radar and Lidar, July 02, Tokyo, Japan		Oral
Krasnov O and H. Russchenberg	2002	The Comparative Study of the Relation Between Cloud Microphysics and Radar-to-Lidar Ratio for the Different Geographical Regions and Field Campaigns	Open Symposium on Propagation and Remote Sensing, 12-15 February 2002, Garmisch - Partenkirchen, Germany	URSI Commission-F, 12-15 February 2002, Garmisch-Partenkirchen, Germany 10 pp	paper
Krasnov O. and H. Russchenberg	2002	The relation between the radar to lidar ratio and the effective radius of droplets in water clouds: An analysis of statistical models and observed drop size distributions.	11th Conference on Cloud Physics, 3-7 June 2002, Ogden, Utah, AMS.		Proc. on CD-ROM
Krasnov O and Russchenberg H	2002	Use of simultaneous radar and lidar data for the retrieval of microphysical parameters in low-level water clouds.	15th Symposium on Boundary Layer and Turbulence, 15-19 July 2002, Wageningen, The Netherlands.	AMS, pp. 88-91.	paper
Krasnov O and Russchenberg H.	2002	Comparison of multiple-wavelength cloud radar observations in the BBC campaign	27th General Assembly of the International Union of Radio Science, Maastrich, The Netherlands.	Conference CD of URSI (2002).	Proc. on CD-ROM