Numerical Weather Prediction

The Met Office Arrival Time Difference (ATD) system for thunderstorm detection and lightning location.

Forecasting Research Technical Report No. 488

Simon J. Keogh, Eric Hibbett, John Nash and John Eyre

email: nwp_publications@metoffice.gov.uk

Revision History.

Date of this revision: 27th June 2006
Date of next revision:

Revision Date	Previous Revision Date	Summary of Changes	Changes Marked
20th June 2006		First issue of V0.1 for review	No
21st June 2006	20th June 2006	V0.2 Integrate JN comments	No
22nd June 2006	21st June 2006	V0.3 Integrate JE+JN comments	No
23rd June 2006	22nd June 2006	V0.4 Integrate JE,JN,EH,NA comments	No
26th June 2006	23rd June 2006	V0.5 Integrate BT comments	No
27th June 2006	26th June 2006	V1.0 Integrate final review from JE.	No

Approvals.

This document requires the following approval.

Name	Signature	Title	Date of Issue	Version
John Eyre		Hd. Satellite Applications		1.0

Circulation.

This document should be circulated to the following.

Name	Title	Date of Issue	Version
John Nash	Hd. Upper Air TC		1.0
Eric Hibbett	Met. Systems Engineer		1.0
Nigel Atkinson	Research Scientist		1.0
Simon J. Keogh	Research Scientist		1.0
Dave Offiler	Hd. SASG		1.0
John R. Eyre	Hd. Satellite Applications		1.0
Bruce Truscott	Space Programme Manager		1.0

Contents.

Executive summary.

The purpose of this document is to present the Met Office Arrival Time Difference (ATD) system and network in terms of their specifications and performance. In addition, planned near-future changes are described and a proposed upgrade to the network to give global coverage is also outlined.

The ATD system is a novel, innovative, low-cost system that was originally designed by the Met Office to provide lightning location data with a nominal location accuracy of ~2km or better for the UK. The ATD system has been operated successfully by the Met Office for nearly 20 years. There are currently eight ATD sensors in the network. Despite being focused initially on providing data for the UK, it is evident that ATD operates very well at much longer ranges, with useful data regularly being obtained from as far away as Central Africa and South America.

The current network is presently being upgraded with new hardware and five extra sites to;

- improve the detection efficiency to >90% of all cloud to ground strokes for UK and Europe
- obtain even better coverage over Africa and the oceans
- reduce the data latency time to just 2 minutes between observation and arrival in Met Office database, to enable rapid dissemination of the data on the GTS

In terms of the services that are provided by a public weather service like the Met Office, ATD is considered to be thoroughly fit for purpose as it delivers clear public benefits at only a modest cost. ATD provides a powerful source of lightning data that can be synergistically combined with Meteosat IR cloud imagery, weather radar imagery, other synoptic data and model data to provide a viable solution to the vast majority of lightning risk/thunderstorm detection applications.

In addition, a proposal is presented in this report to extend globally the coverage of the ATD system – at a cost of less than £500K (€700K/$850K). Global coverage can be obtained within 3 years with just 17 more ATD sites. This would bring the total number of ATD sites to just 30 to cover the entire globe. Several nations have recently expressed an interest in hosting ATD sites due to the low-cost, reliable nature of the system compared to expensive, short-range, commercial alternatives.

1. Introduction.

The purpose of this document is to present the Met Office Arrival Time Difference (ATD) system and network in terms of their specifications and performance. In addition, planned near-future changes are described and a proposed upgrade to the network to give global coverage is also outlined.

The Arrival Time Difference (ATD) thunderstorm detection system is a low-cost innovation that has grown out of a requirement placed on the UK Met Office to accurately locate thunderstorms. A list of customers and their requirements is shown in table 1.

Table 1. Main customers for ATD data.

Customer	Application	Accuracy Requirement
General weather prediction	Locating thunderstorms	Location accuracy of <5km
National Electricity Supply Grid	Fault finding	Location accuracy of 1-2km
Insurance companies	Validation of insurance claims	Location accuracy of 1km

The ATD system has been designed to give a nominal accuracy for the UK of 2km for lightning location, though higher accuracy is generally obtainable. The accuracy requirement is so stringent primarily because some of the most destructive thunderstorms can be small in size (2-5km). In most cases the location accuracy is around 1km over the UK, which enables the data from ATD to also fulfil the needs of commercial parties with more demanding requirements than the public weather forecast customers e.g. Insurance companies.

The ATD system works by detecting the vertical component of the electromagnetic field generated by a lightning discharge at a frequency of around 10 kHz received by a minimum of 4 sensor sites. These strong EM emissions at 10 kHz are caused by rapid neutralisation of charge, in the lowest few hundred metres of cloud to ground (C-G) strokes. The atmospheric attenuation minimum close to 10 kHz allows the atmoSFERIC wave to propagate over thousands of kilometres along the earth/ionosphere waveguide. The ATD system does not sense cloud to cloud (C-C) strokes. This may at first appear to be a disadvantage. However, in so far as weather forecasting is concerned, it is the C-G strokes that are of paramount importance. Significant extra benefits are not expected from sensing C-C activity. Therefore, ATD has not been developed with this in mind as a priority because C-G detection satisfies the majority of thunderstorm location and detection applications.

The ATD thunderstorm detection system currently consists of a network of eight ATD sensor sites to provide lightning detection and location over three specific “service areas”;

- British Isles and North Sea
- All of Europe and Eastern Atlantic
- Global area from 70N to 30S as far as is possible

ATD became operational in 1987. ATD replaced an earlier lightning location system, based on direction finding at 10kHz, that had been operational for 40 years. System upgrades in the late 1990s allowed automation to be possible and from early 2000 the system has operated almost autonomously but under the supervision of the network manager during normal working hours and by Network & Engineering staff at other times. The upgrades also gave performance improvements, coupled with changes to the network geometry, resulting in a much-improved total service area with reliable coverage being gained over the Caribbean & South America plus more of Africa down to about 10S in the west.

2. The current ATD system and network.

2.1 Description

The present network consists of eight ATD sensors operating in the European area. The distribution of the ATD sensors is shown in figure 1. Coverage is not limited to the European area though. As previously mentioned, useful data are regularly obtained from as far away as South America. Figure 2 shows the estimated current performance "service area" obtained by comparing two months of data with data from the LIS (Lightning Imaging Sensor) satellite climatology.

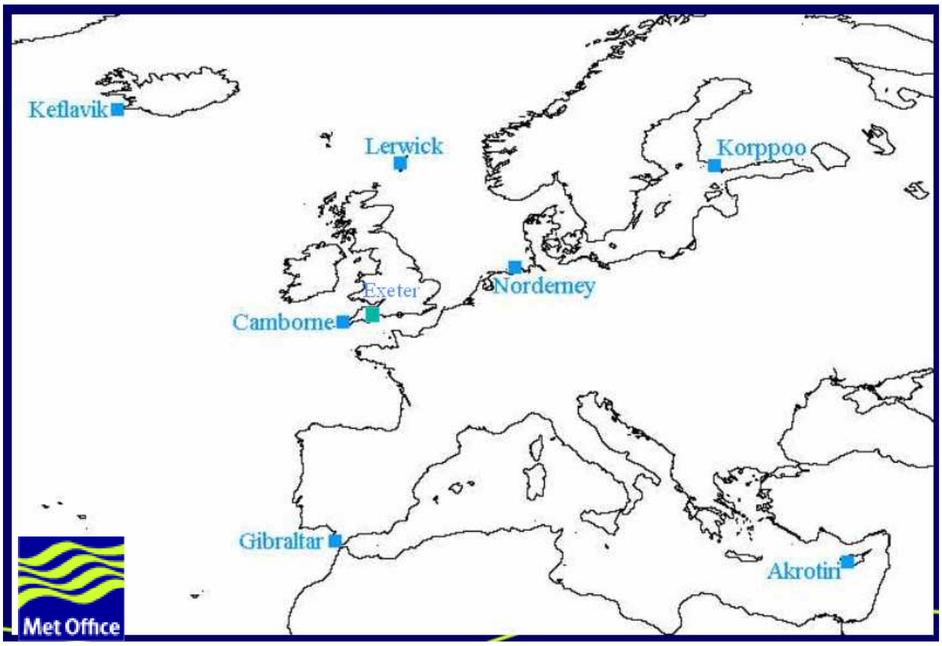


Figure 1. Present locations of ATD sensors.

The ATD sensor is basically an antenna that picks up VLF radio signals from cloud-ground lightning strikes. The antenna is coupled to a processing electronics unit that detects the lightning events, filters the incoming signals (selecting the frequency range 5-15 kHz) and encodes the sferic waveforms in a highly compressed form. The outstation then uses conventional (or custom) telecommunications lines to transmit the encoded waveforms and their arrival times back to Exeter. In the Control Station at Exeter, waveforms from each site are compared with waveforms from a selector station, using a correlation technique, and the arrival time differences are computed. From these time differences, the location of each lightning strike is then computed. It is worth mentioning here that the new system being rolled out during 2006, will not use a selector station and so will have a much increased detection efficiency. This will eliminate past problems associated with reduced efficiency during the summer months when the network was saturated with more data than it could handle.

The current ATD system routinely produces 5-minute high-resolution output messages for internal Met Office utilisation plus half-hourly "WMO" messages for distribution by the GTS. A number of "area cut-outs" are produced for commercial customers and for other European Met Services in exchange for them "hosting" an ATD sensor at one of their sites.

2.2 Performance

The performance of the current ATD network is truly remarkable given a) the low cost of the system in place and b) the locations of the systems being currently concentrated in the UK/European area. The performance of the current ATD network is summarised in table 2.

Table 2. Summary of performance characteristics for **current** ATD system.

Type of lightning detected	Cloud to ground
Horizontal resolution	2-3km fix accuracy over the UK 20-40km fix accuracy at extreme range (outlined in figure 2) with current ATD network
Detection efficiency	70-90%(winter) and 20-90% (summer) for UK and Europe with 10-70% for Eastern Europe, 80% N. Africa to 0% in S. Africa. Summer/winter difference due to flash/hour limit saturation in summer time
Timeliness of data	Arrival in database within 15 minutes, 30 minutes GTS reports
Number of flashes per hour limit	12,000

The useful coverage of the current ATD system is show below in figure 2. The range is greatest to the South West of the UK due to the high efficiency of the propagation of low frequency radio waves through the ocean/ionosphere wave guide.

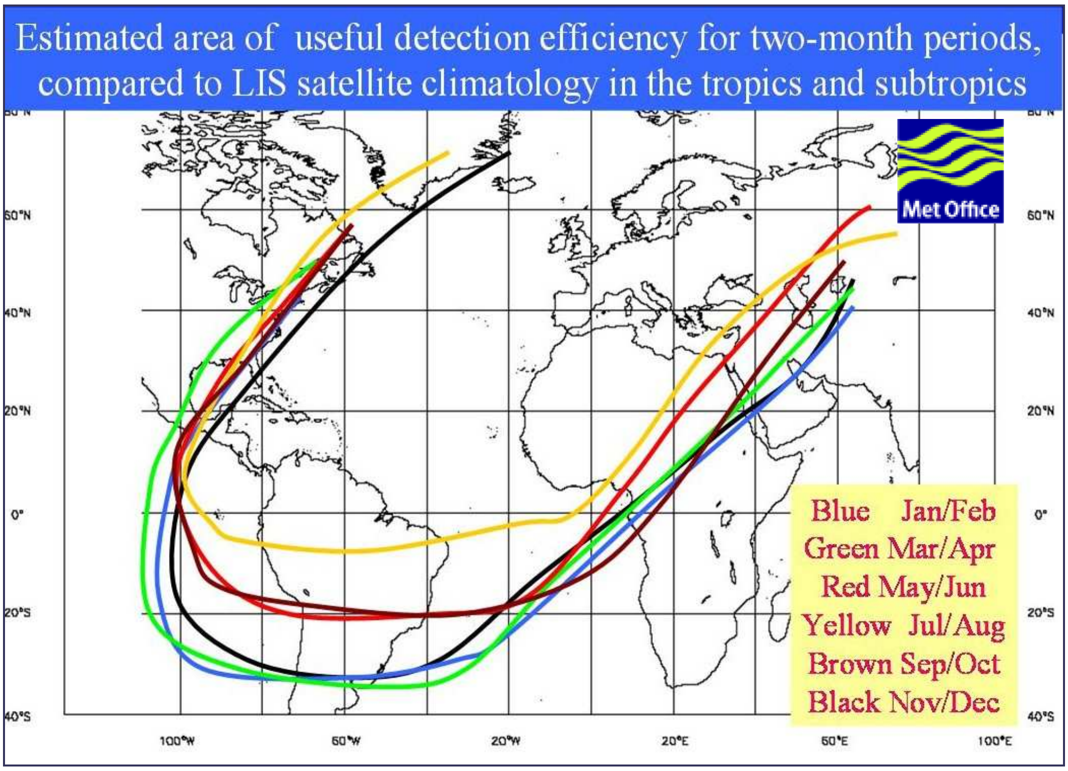


Figure 2. Current performance service area.

The coverage over the METEOSAT domain is demonstrated in the following two figures. In these figures, recent infrared cloud imagery is augmented by overlaying the previous six hours of ATD sferic data. The first figure (figure 3) shows the passage of a thunderstorm over the UK (close to Met Office headquarters). The second figure (figure 4) demonstrates the remarkable ability of ATD to monitor thunderstorm activity in the inter-tropical convergence zone (ITCZ) – many thunderstorms can be seen over Africa. Longer range coverage is illustrated by figure 5 (1 hour of global data). Further interesting imagery of Africa and South America can be seen in Annex 1.

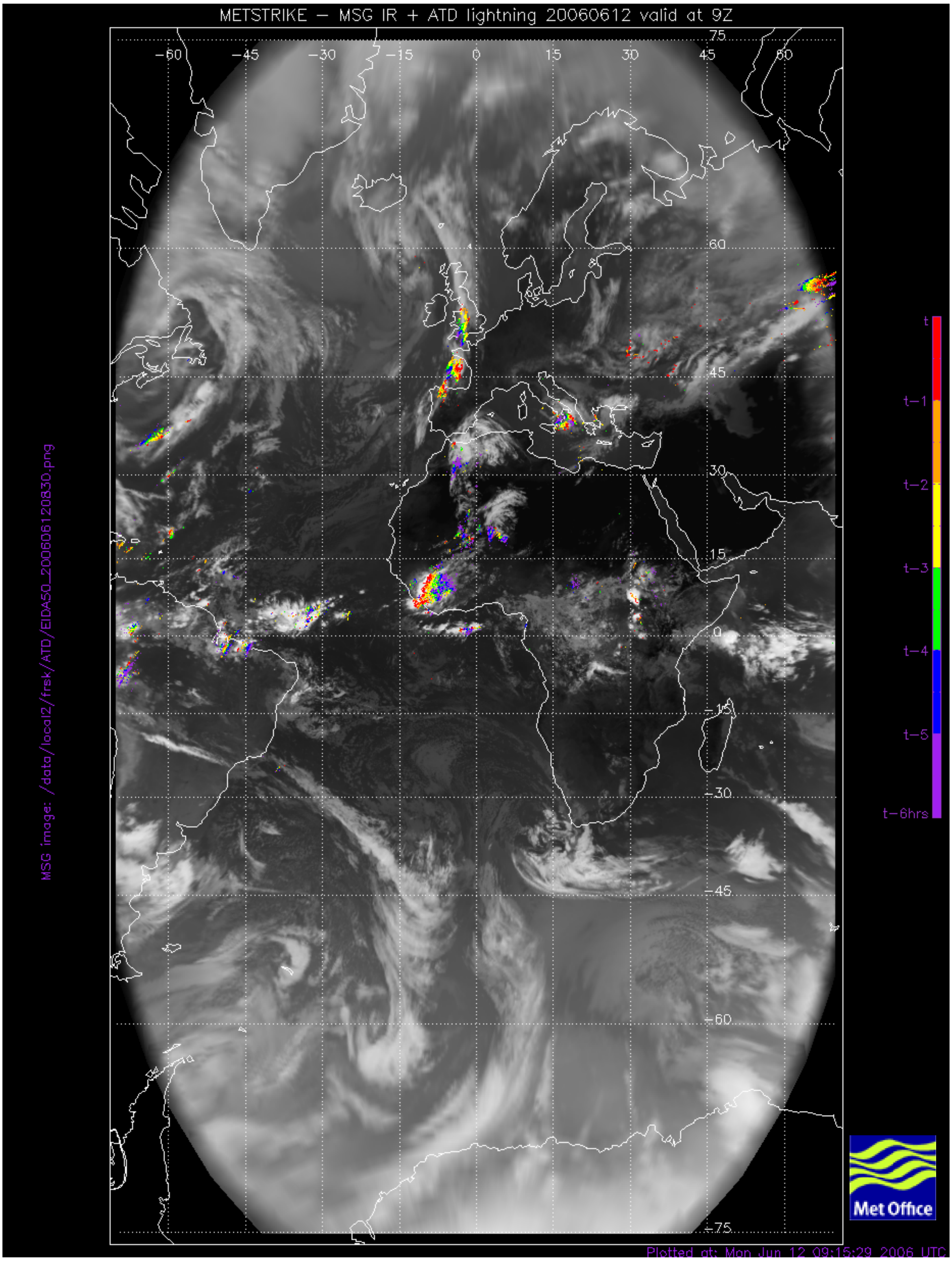


Figure 3. Example ATD data showing thunderstorm storm passage over the UK. The colour scale is red (data in the last hour, t to t-1) through to purple (data between t-5 and t-6 hours).

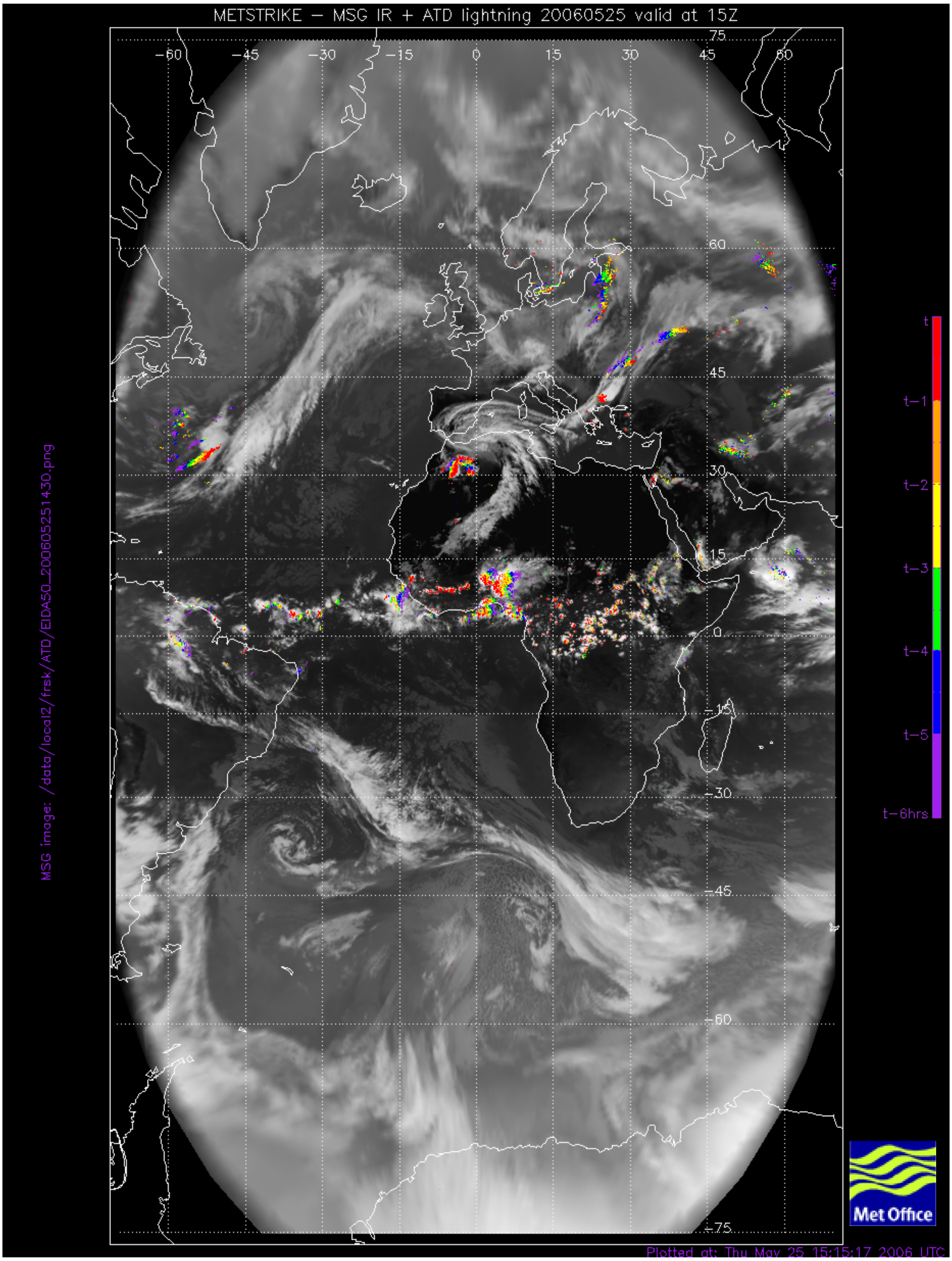


Figure 4. Example ATD data showing coverage of thunderstorms over Africa. The colour scale is red (data in the last hour t to t-1 hour) through to purple (data between t-5 and t-6 hours).

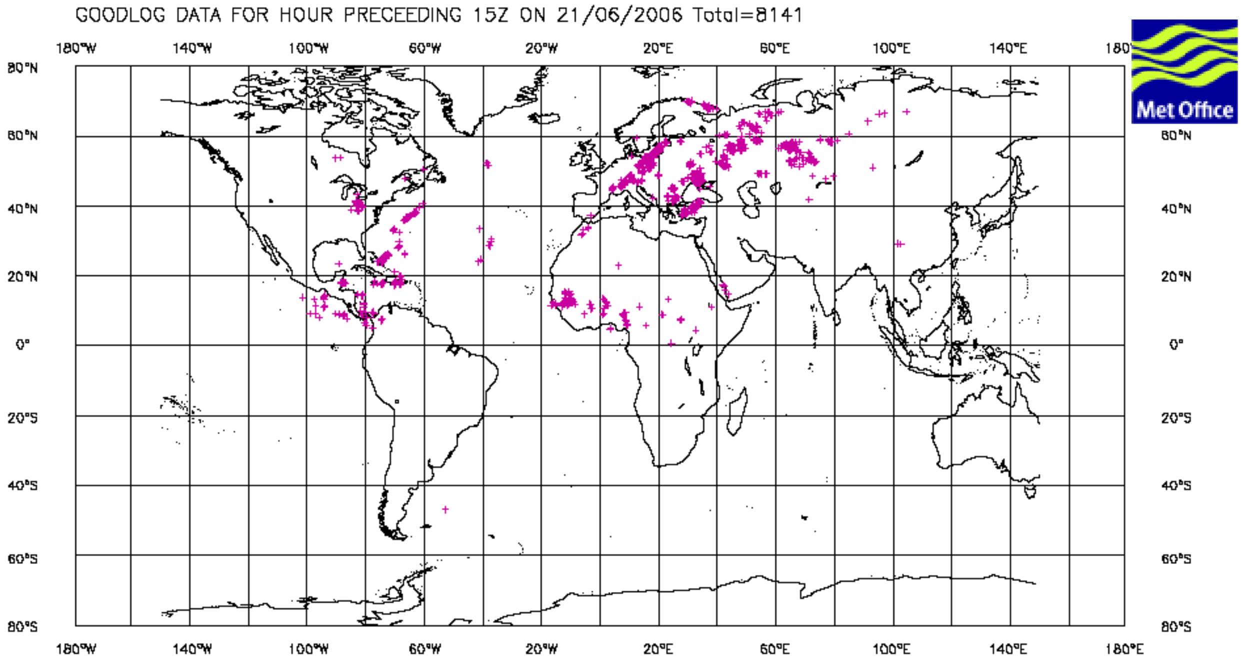


Figure 5. Global performance of **current** ATD system.

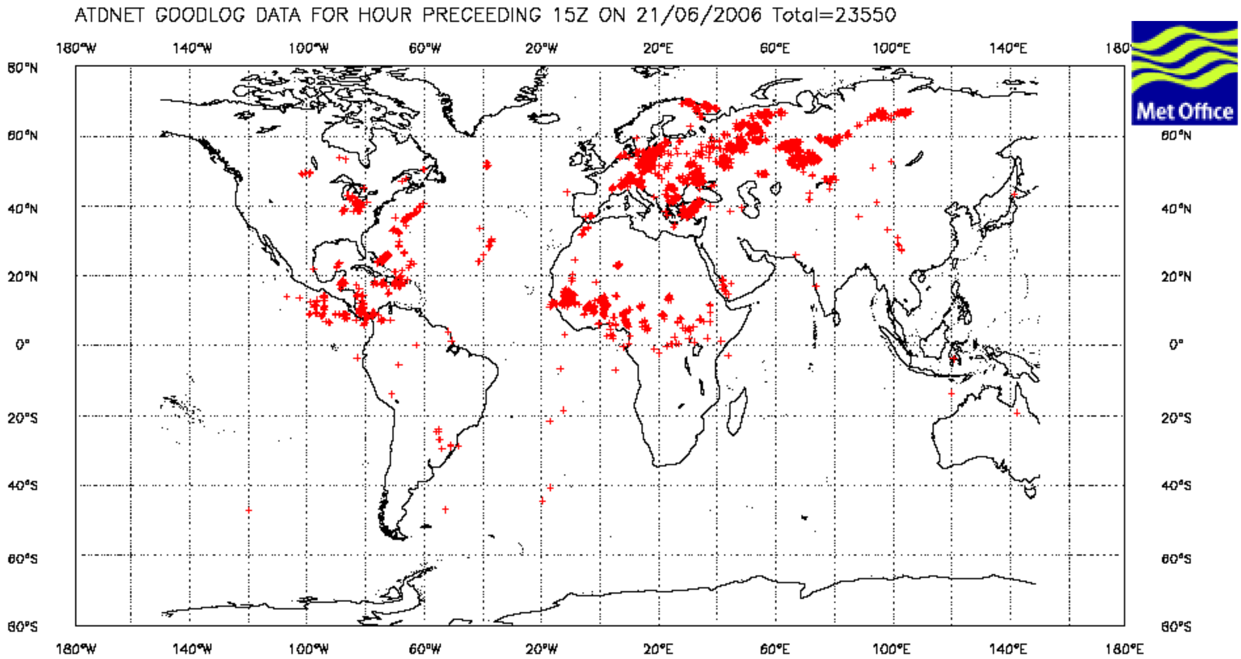


Figure 6. Global performance of **new** ATD system running in parallel with old system, but without the new sites added. Note increased SFERICS detection by a factor of 3 compared to current system in figure 5.

3. Planned ATD system and network improvement up to 2007.

A project is currently underway to upgrade the ATD network by the end of 2007. This project is aiming to;

- Replace current sensors with updated hardware
- Extended coverage, particularly over Africa and the ocean
- Use internet ftp for data delivery rather than the existing, expensive telecoms solution

The project also aims to add new sensors sites in;

- South Africa
- The Azores
- Indian Ocean
- Republic of Ireland
- 1 other possibility, as yet not approached

The project has so far succeeded in producing the new hardware, which is now currently running in parallel with the old sensors on the current network sites (figure 1). The coverage provided by the upgraded hardware is shown in figure 6. It is interesting to note that the global detection efficiency has increased by a factor of three (compare with figure 5) despite no extra stations being added as yet. This is due to the flash limit of 12,000/hour being increased to 200,000/hour by the use of better technology. When the new stations are added to the network, the resulting distribution of ATD sensors will be that shown in figure 7. Annex 2 shows photographs of the new ATD hardware at Norderney, Germany. The expected performance of the new network with both upgraded hardware and extra sites is shown in table 3.

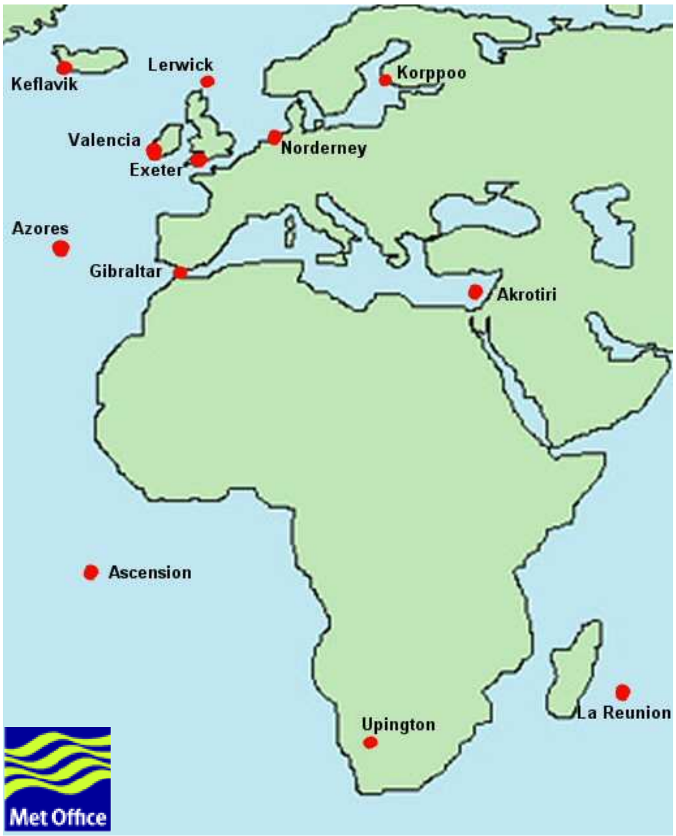


Figure 7. Planned ATD network coverage for 2007.

Table 3. Planned performance **improvements** to ATD system and network.

Type of lightning detected	Cloud to ground
Horizontal resolution	2-3km fix accuracy over the UK and Europe Even better coverage over Africa with <5km fix accuracy expected.
Detection efficiency	>90% for UK and Western Europe, with no difference in detection efficiency between summer and winter. Eastern Europe expected 70% detection efficiency. Over Africa and ITCZ, though hard to quantify exactly how much at present, 50% detection efficiency is expected and with two additional sites this could be raised to 80% detection efficiency over all of Africa.
Timeliness of data	Data available in central database within 2 minutes
Number of flashes per hour limit	200,000 so no saturation during summer

The resolution and data latency figures in table 3 compare favourably with those in Annex 3, which are related to user requirements for 2015-2025.

4. Proposed global network coverage.

4.1 Proposed network.

It is exciting to note that the ATD thunderstorm detection network can be readily expanded to provide global, or very near global, coverage in a relatively short timescale (2 to 3 years). This can all be achieved at a very modest cost by the addition of more ATD sensors into the network in new locations.

Several network configurations have already been produced. One of the most comprehensive network designs considered so far was a global network with 17 extra stations (giving a total of 30 worldwide) to provide enhanced global detection efficiency. Figure 8 shows the proposed network structure. The anticipated performance of the global network is shown in table 4.

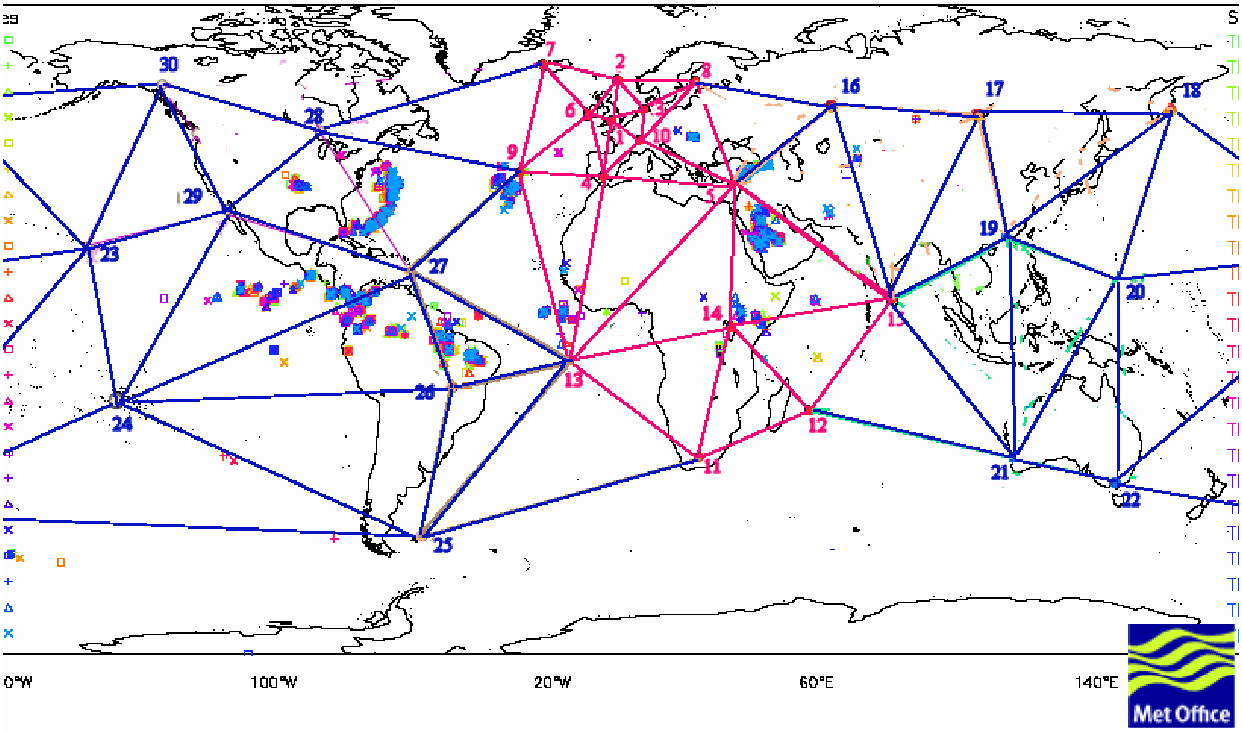


Figure 8. Alternative design for a global ATD network, with 17 more ATD sensors.

Table 4. Anticipated performance of **proposed** global network.

Type of lightning detected	Cloud to ground
Horizontal resolution	2-3km fix accuracy over the UK and Europe <10km fix accuracy expected elsewhere
Detection efficiency	>90% for UK and Western Europe >50% for rest of the world
Timeliness of data	Data available in central database within 2 minutes
Number of flashes per hour limit	500,000

A list of potential sites to make up a global network can be found in Annex 4. The list is by no means exhaustive and is only meant to be a guide rather than an outline of a firm plan.

4.2 Costs of a global ATD thunderstorm detection network.

To give some idea of the cost of such a system, some estimates are provided below. The costs can be broken up into a) setup costs and b) running costs.

a) Setup costs.

Equipment cost - ca £11K per ATD sensor system; broken down as follows:

Sensor	2.0
PC	1.0
Signal acquisition and timer cards	3.0
Suppressor Junction Box	1.0
Interface Unit	4.0
Sub-total	11.0

Construction cost	4.0
Installation cost	10.0
Comms setup	1.0
Total/site ca	£26.0K

This shows demonstrates that a network with 30 stations (17 added to already operational/planned list) can be constructed for a cost of £490K, which is approximately €686K or $833K US[1]. These setup costs would be distributed globally amongst ATD partners meaning that the actual cost to any 1 partner would be small.

b) Running costs.

Running costs may be broken down into 2 areas; communications costs and support comprising maintenance and repair.

- Communications costs: It is difficult to put a definite cost of an internet based communications link but it is estimated that the cost for rental of a line to a local Internet Service Provider (ISP) will be in the order of £30 to £100 per month. Thus the monthly cost of a network of 30 ATD stations will be in the order of £3k in the worst case giving an annual cost in the order of £35K.

- Support costs: Since the new ATD functionality can be monitored remotely, most potential problems can be identified from Exeter. Thus in general most failures will be rectified by unit substitution thus minimising technical requirements and knowledge on site. Therefore the majority cost will be carriage of replacement units and possibly some provision for local staff cost dependent on the agreement with the host NMS/organisation etc. It is anticipated that the requirement to visit the ATD host site from the UK will be minimal but some allowance should be made. Thus, it is estimated that support costs would be in the region of £20K to £50K per annum for the network.

[1] Approximate currency conversions used here are £1=€1.4=$1.7

5. Summary.

The ATD system is a novel, innovative, low-cost system that was originally designed by the Met Office to provide lightning location data with a nominal location accuracy of ~2km or better for the UK. The ATD system has been operated successfully by the Met Office for nearly 20 years. There are currently eight ATD sensors in the network.

The main features of the ATD thunderstorm detection system are:

- Good UK/European coverage obtained with only eight sensors, even at high latitudes
- Expected >90% detection efficiency for UK/Europe when upgrades are complete in 2007
- Low set up and running costs
- Potential for global coverage, partial global coverage already available
- Ground-based technology
- Oceanic coverage
- Data delivered to GTS for sharing with national meteorological services
- Data can be readily used in value added products

Despite being focused initially on providing data for the UK, it is evident that ATD operates very well at much longer ranges, with useful data regularly being obtained from as far away as Central Africa and South America. The new upgraded ATD network will be delivering >90% detection efficiency and location accuracy of <3km for the UK/Western European area when the upgrades are complete in 2007. The current network is currently being upgraded with new hardware and five extra sites to;

- improve the detection efficiency to >90% of all cloud to ground strokes for UK and Europe
- obtain even better coverage over Africa and the oceans, resulting in a fix accuracy of 2-3km and a detection efficiency of 50% or better over Africa
- reduce the data latency time to just 2 minutes between observation and arrival of data in central database

Low set up and running costs (as shown in section 4.2) combined with a high detection efficiency make ATD a good choice for providing an affordable thunderstorm detection system for global applications. The data can be readily used in value-added applications and synergistically combined with data from a variety of sources such as; METEOSAT cloud imagery, weather radar imagery, satellite data, numerical model output and other synoptic data. This provides viable solutions to the vast majority of lightning risk/thunderstorm detection applications. It is estimated that a global network of ATD sensors could be realised within 3 years at a cost of less than £500K (€700K/$850K). Global coverage (including the oceans) can be obtained with just 17 more ATD sites than are currently already operating or planned for commissioning within the next 12 months. This would bring the total number of ATD sites to just 30 to cover the entire globe. Several nations have recently expressed an interest in hosting ATD sites due to the low-cost, reliable nature of the system compared to expensive, short-range, commercial alternatives. Table 5 summarises the expected performance of ATD post 2007 for different world areas.

Table 5. ATD capability post-2007 (HR=Hit Rate, FAR=False Alarm Rate).

Area, network (planned/proposed)	Accuracy	Location	Time delay
UK+Western Europe, using *planned* network	90% HR, <10% FAR	2-3km	2mins
Eastern Europe, using *planned* network	70% HR, <10% FAR	2-3km	2mins
Africa, using *planned* network	50-80% HR, <10% FAR	<5km	2mins
Rest of the world outside UK and Western Europe with *proposed* global network (see section 4)	>50% HR, <10%FAR	<10km	2mins

In terms of the quality of the products that are provided by a public weather service like the Met Office, ATD is considered to be thoroughly fit for purpose as it delivers clear public benefits at only a modest cost. The success of the system over the last 20 years will be built upon in future with the upgraded network in 2007 and the potential future expansion of the network in the coming years ahead.

6. Bibliography.

N. Daly, J. Nash, E. Hibbett, G. Callaghan and P. Taylor; "Results from the upgraded ATD Sferics lightning detection system of the Met Office (UK)." International Conference on Lightning Detection, Tucson, Arizona, November 2000.

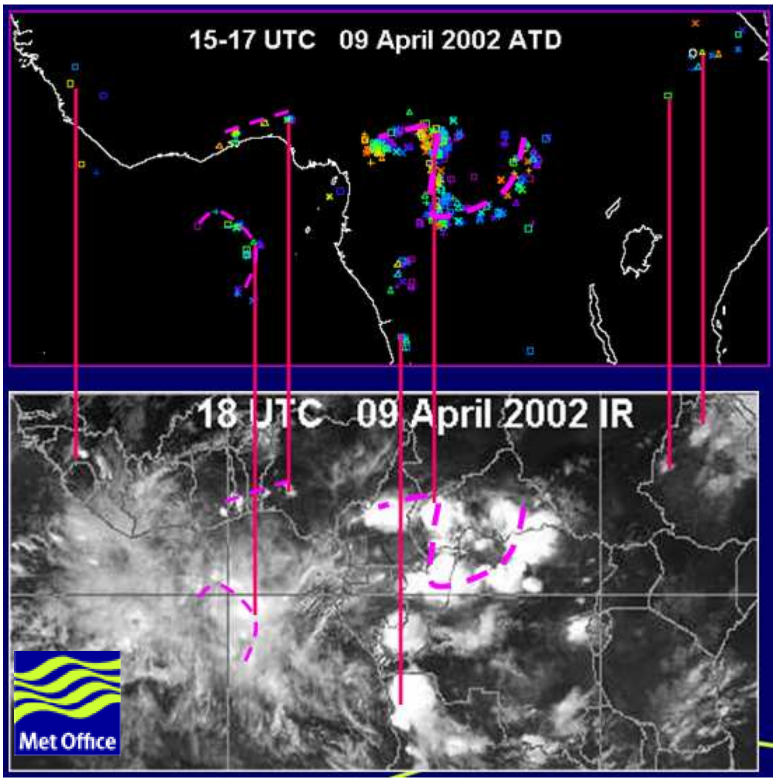
B.W. Golding, S. Senesi, K. Browning, B. Bizzarri, W. Benesch, D. Rosenfeld, V. Levizzani, H. Roesli, U. Platt, T.E. Nordeng, J.T. Carmona, P. Ambrosetti, P. Pagano, M. Kurz, "EUMETSAT Position Paper on Observation Requirements for Nowcasting and Very Short Range Forecasting in 2015-2025", V11.02 05/12/2005. EUMETSAT Report.
http://www.eumetsat.int/groups/pps/documents/document/pdf_mtg_aeg_nwc_positionpaper.pdf

A.C.L. Lee (1986), "An operational system for the remote location of lightning flashes using a VLF arrival time difference technique" Journal of Atmospheric and Oceanic Technology, Vol. 3, No. 4

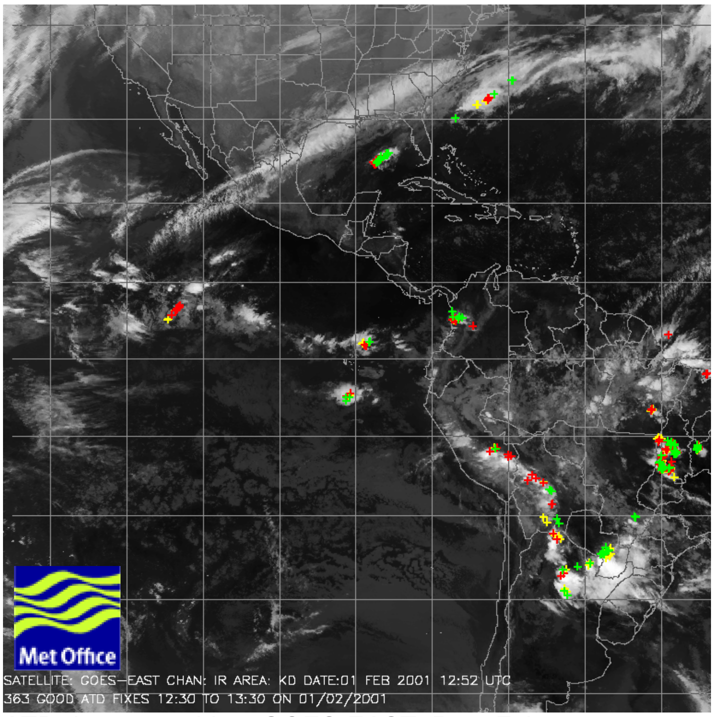
A.C.L. Lee (1989), "Ground truth confirmation and theoretical limits of an experimental VLF arrival time difference lightning flash locating system" Quart. J. of the Royal Met. Soc., Vol. 115, No. 489.

J. Nash, N.C. Atkinson, E. Hibbett, G. Callaghan and P.L. Taylor, "Progress in introducing new technology sensor sites for the Met Office long-range lightning detection system", Paper 2.9 in the Proceedings of the WMO Technical Conference on Instruments and Methods of Observations, Bucharest, Romania. 4-7 May 2005. IOM Report 82, WMO TD 1265., 2005.

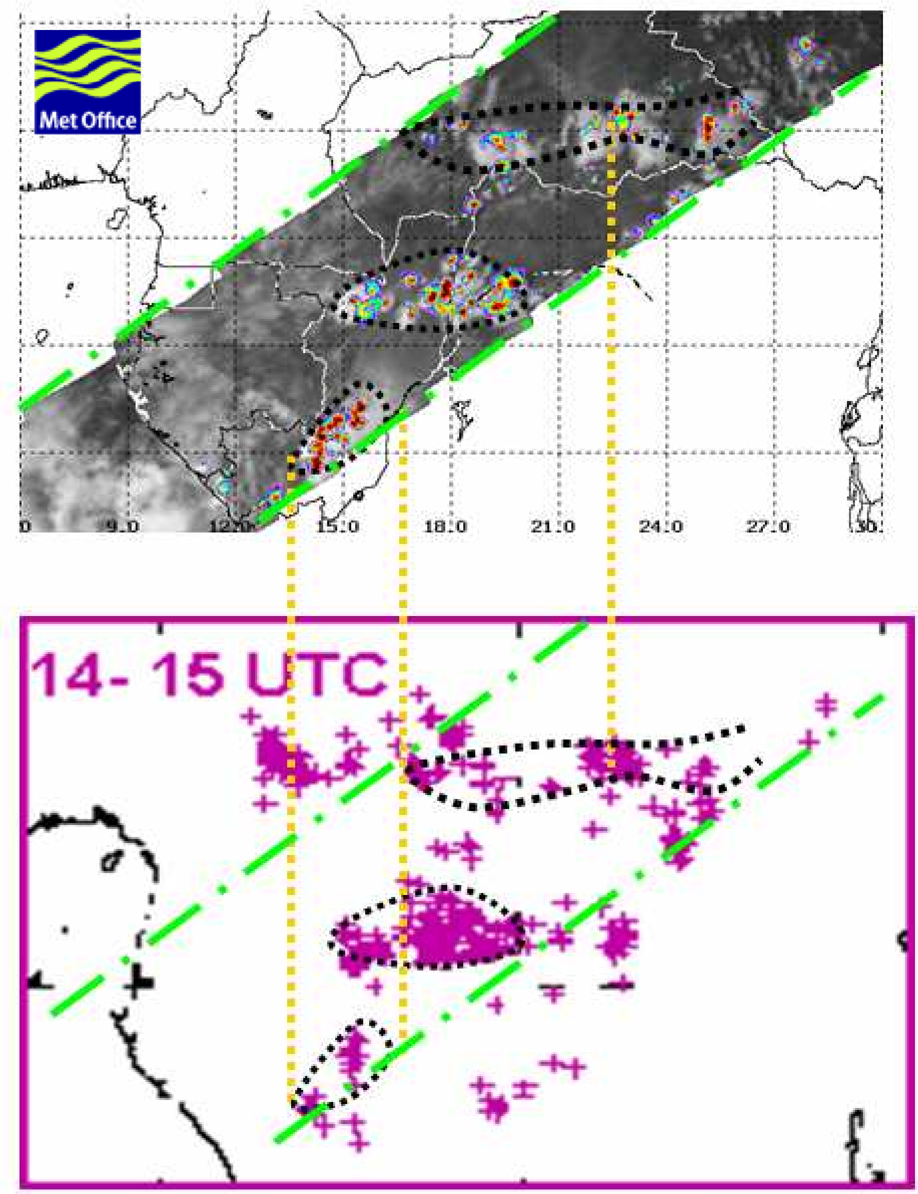
Annex 1. Interesting imagery.



ATD data over Africa collocated with IR imagery from 2002.



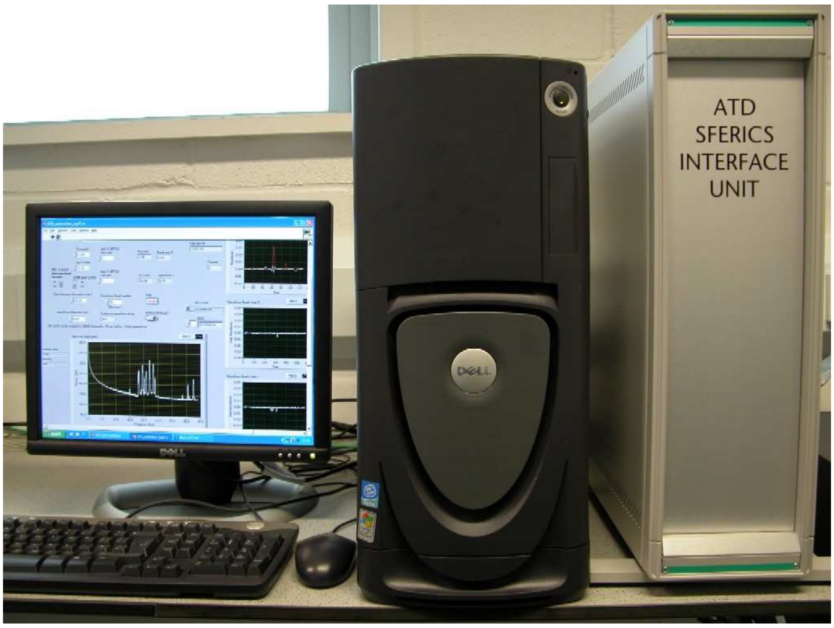
ATD data overlaid on GOES-EAST IR 01 February 2001 1300 UTC.

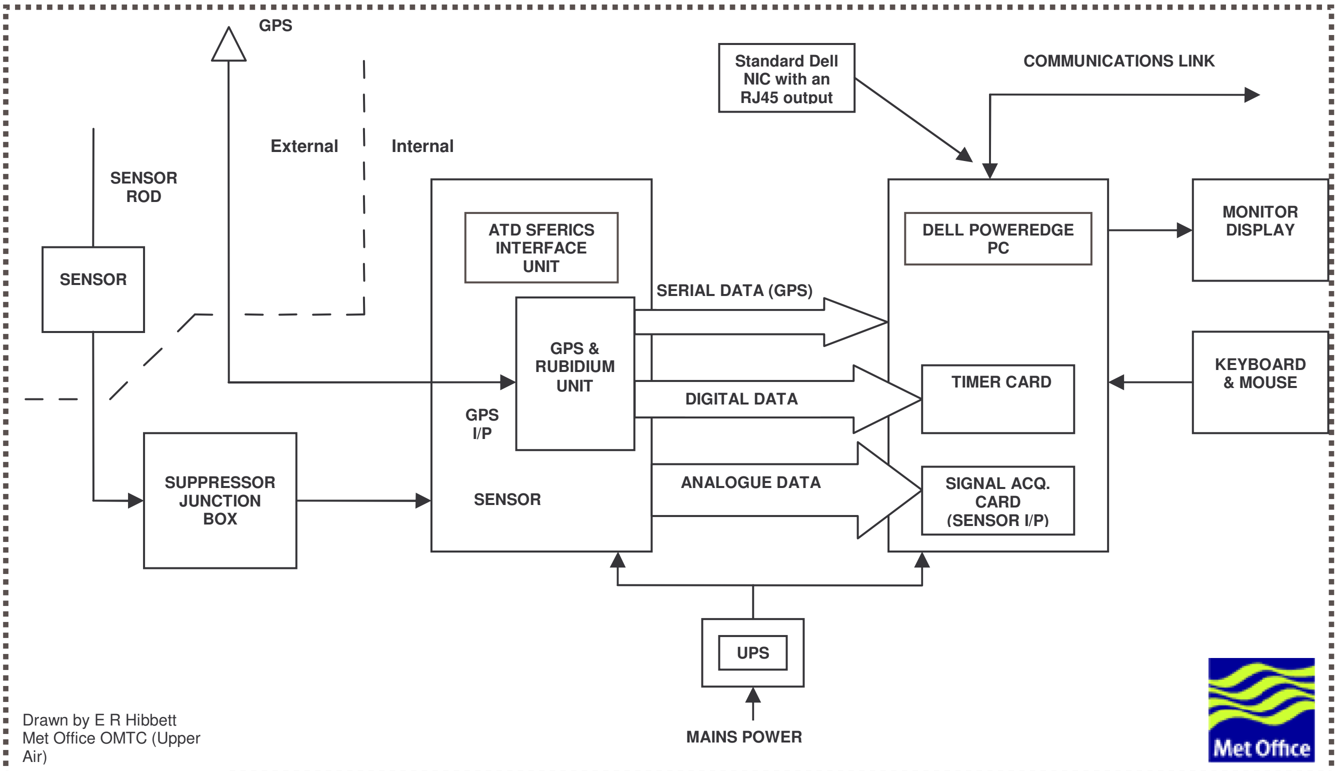


Comparison with imagery from LIS over Africa (Gabon-Central African Republic) on 9th April 2002 using the current ATD system.

Annex 2. Overview of new ATD system.

The photos below show the essential installation components of the ATD sensor system. Left: The computer workstation and signal processing package. Right: The ATD antenna. ATD is essentially very compact and non-intrusive in the landscape. This new hardware is at Norderney, Germany. Lower: ATD sensor system diagram.





Annex 3. Requirements for lightning observations 2015-2025.

The table below is a summary taken from a EUMETSAT report by Golding et al., “EUMETSAT position paper on Observation Requirements for Nowcasting and Very Short Range Forecasting in 2015-2025”.
http://www.eumetsat.int/groups/pps/documents/document/pdf_mtg_aeg_nwc_positionpaper.pdf

Lightning observation requirements for applications related to Nowcasting and Very Short Range forecasting.

Forecast method	Required variable	Applications	Accuracy threshold	Accuracy optimum	Location threshold	Location optimum	Report frequency threshold	Report frequency Optimum	Delay threshold	Delay optimum	Priority level
Observation & extrapolation	Electrical discharges	Life, Fuel/explosives handling	30% HR (90% for isolated events) 10% FAR	90% HR 10% FAR	10km	1km	15min	5min	5min	2min	H
Convection forecasting techniques	Lightning intensity	Indicator of hail intensity	30% HR 10% FAR	90% HR 10% FAR	2km land 5km ocean	1km	15min	1min	5min	1min	H
Dispersion Chemistry and biology models	Lightning location	Natural NOx formation	-	-	10km	1km	1hr	15min	30min	15min	M

HR = Hit Rate
FAR = False Alarm Rate
H = High
M = Medium

A technology breakthrough level for *electrical discharge* and *lightning intensity* measurement is viewed as; 50% HR, 10% FAR, 2km location accuracy (land), 3km location accuracy (ocean), 15 minute temporal resolution. This level is deemed to be that which would provide a significant advance in forecasting capability relative to that in 2003 or likely to be available before 2015.

Note that percentages on this page refer to total lightning (C-G and C-C) rather than just C-G.

Annex 4. Example list of sites that could make up a global ATD network.

	Site	Site status
1	Exeter	Site active
2	Lerwick	Site active
3	Norderney	Site active
4	Gibraltar	Site active
5	Akrotiri (Cyprus)	Site active
6	Valentia (Ireland)	Site active
7	Keflavik (Iceland)	Site active
8	Korppoo, Finland	Site active
9	Angra do Heroismo (Azores)	Agreement being sought
10	Payerne, Switzerland	No formal approach made yet
11	Upington (South Africa)	Agreement being sought
12	La Reunion	Agreement being sought
13	Ascension Island	Agreement being sought
14	Uganda or Tanzania	No formal approach made yet
15	Sri Lanka	No formal approach made yet
16	Hong Kong	No formal approach made yet
17	Perth, Australia	No formal approach made yet
18	Falkland Islands	No formal approach made yet
19	Barbados	No formal approach made yet
20	Brasilia	No formal approach made yet
21	Novosibirsk	No formal approach made yet
22	Hanoi	No formal approach made yet
23	Sapporo	No formal approach made yet
24	Nova Scotia	No formal approach made yet
25	Winnipeg	No formal approach made yet
26	Juneau [Alaska]	No formal approach made yet
27	San Diego	No formal approach made yet
28	Hawaii	No formal approach made yet
29	Tahiti	No formal approach made yet
30	Guam	No formal approach made yet
31	Townsville or Cairns	No formal approach made yet
32	Perth	No formal approach made yet
33	Hobart	No formal approach made yet
34	Cocos Island	No formal approach made yet

Annex 5. Glossary of acronyms.

ATD	Arrival Time Difference
C-C	Cloud to cloud strokes
C-G	Cloud to ground strokes
EM	Electromagnetic
GPS	Global Positioning System
GTS	Global Telecommunications System
ITCZ	Inter-Tropical Convergence Zone
LIS	Lightning Imaging Sensor
NWP	Numerical Weather Prediction
UPS	Uninterruptable Power Supply
VLF	Very Low Frequency