OCCASIONAL PAPERS ON METEOROLOGICAL HISTORY No.4

METEOROLOGY
AND
AERIAL NAVIGATION

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Published by
THE ROYAL METEOROLOGICAL SOCIETY
Specialist Group for the History of
Meteorology and Physical Oceanography

SEPTEMBER 2002

ISBN – 0 948090 20 0

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PREFACE

This paper is based on an article written for the Royal Institute of Navigation's History of Air Navigation Group and was accepted for the Institute's quarterly *Journal of Navigation*. The original commission came from Walter Blanchard, former President of the RIN. Malcolm Walker is thanked for converting it into this Occasional Paper.

Meteorology and aerial navigation

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THE EARLY DAYS

INTRODUCTION

According to the Concise Oxford Dictionary, ***aerial navigation*** is the "method of determining ... aircraft's position and course by geometry and nautical astronomy ..." and ***meteorology*** is the study of motions and phenomena of the atmosphere. Strictly, then, there is no direct connection between the two, but, in reality, the atmosphere is the environment in which aircraft operate; and whatever flies is totally dependent upon the air - not least to hold it up! Whether the "motions and phenomena" work with or against the aviator, they cannot be ignored. He or she has three options: to take advantage of favourable conditions; to avoid dangerous situations; to compensate for the intermediate effects. It should be remembered in this context that the atmosphere is four dimensional, since it changes at variable rates with the passing of time. If the atmosphere were stationary and clear at all times, navigation would be a simple automatic process. During the earliest manned flights in the late 18th century, navigation was largely a matter of luck, but by the late 20th century almost every aspect had been computerised, and sophisticated systems had automated most of the routine tasks. Between the two extremes, however, there were two centuries of learning about interactions between the weather and flying.

BALLOONS

Figure 1
Dr John Jeffries

It is generally accepted that the earliest flight undertaken to study the atmosphere was the third balloon flight in England, i.e. the one made from London to Kent on 30 November 1784 by Dr John Jeffries (Fig.1) and Monsieur Jean-Pierre Blanchard (who was perhaps the first professional aviator). Reputedly, Dr Johnson approved of the new phenomenon but thought "The vehicles can serve no purpose till we can guide them". He must have been a navigator at heart.

In his account, Jeffries (1786) was at pains to explain his motives in seeking permission to accompany M. Blanchard on a flight. He said:

> "I wished to see the following points more clearly determined: First, the power of ascending or descending at pleasure, while suspended, and floating in the air. Secondly, the effect which oars, or wings, might be made to produce towards this purpose, and in directing the course of the Balloon. Thirdly, the state and temperature of the atmosphere at different heights from the earth: And Fourthly, by observing the varying course of the currents of air, or winds, at certain elevations, to throw some new light on the theory of winds in general."

From the earliest days of flying, the problems of navigation and meteorology were inextricably entwined. First, a small balloon was launched "to ascertain the course we probably should take" – one of the earliest recorded pilot balloons and a recognition of the need for flight planning. Jeffries and Blanchard clearly had some idea of what they were doing as they were the first to fly across the Channel a couple of months later.

A contemporary of Jeffries, Thomas Baldwin, published *Airopaidia*, which was probably the first book on aviation meteorology (Baldwin, 1786). In this, he recounted his flying experiences with Lunardi (the first balloonist to fly in England) and claimed to provide "an introduction to aerial navigation". It was certainly not navigation in the specialised sense that 20th century professionals understood, but it did address the problems as summarised thus:

> "But to acquire a Certainty of the Course, it will be proper to descend below the Cloud: or move by Compass, Map, and a Knowledge of the Country: or try the long Cable. It is likewise necessary to know the Signs of Wind or Currents of Air."

He was aware of winds differing at different heights and to measure this he dangled flags on half a mile of twine. He also used thin ribbon, balloons and feathers to show the rise and fall in vertical currents. He noted clouds moving in different directions and raised or lowered the balloon to choose a safe course; he also knew about the sea breeze and its diurnal variation by observing direction of smoke from houses. He even commented on what we now know to be a temperature inversion.

In 1838, Thomas Monck Mason addressed the problems of aerial navigation in *Aeronautica*. (Mason, 1838). Appendix D is entitled "Observations upon the mechanical direction of the balloon". He attempted to discuss the mechanics of the problem in a more "scientific" manner, but his verbosity obscures the fact that little real progress was made in the first half century of manned flight.

In 1840, Charles Green wrote *Aerostation: Inquiry into the uses and capabilities of the balloon-projected voyage across the Atlantic and etc.* and Joseph MacSweeny wrote *An essay on Aerial navigation, pointing out modes of directing balloons* (2nd edition, 1844). The effort and investment of the technology used to complete successful long range balloon flights in the late 20th century emphasises the blind optimism of the 19th century fliers.

DIRIGIBLES

The first practical, steerable or dirigible airships were made in the 1880s. One of the first to fly under control was made by Renard and Krebs near Paris in 1884 (Fig.2) and was powered by an electric motor. Also in 1884, a German inventor named Ganswindt published plans for a giant airship 500ft long by a diameter of 50ft with a 100hp motor. This was much larger than anything ever previously suggested and may well have been the inspiration for Count Zeppelin, who became actively interested in airships in 1887. In the years that followed, his factory in Frankfurt produced hundreds of airships, and these carried thousands of passengers safely before the Great War. Zeppelin showed how to do it and Britain tried to copy - with only limited success.

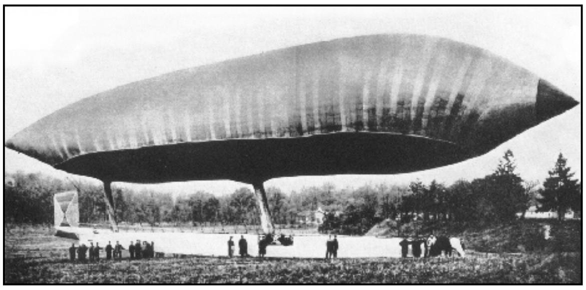

Figure 2
The first practical dirigible

AEROPLANES ARRIVE

On 17 December 1903, Wilbur and Orville Wright demonstrated the feasibility of powered, manned flight in a heavier-than-air machine, but after four successful, if short, flights a gust of wind overturned their craft causing some damage. Thus, from the very start it was clear that meteorology played an important part in safe flying operations.

Aeroplane flights during the first few years of manned flight were little more advanced than those of the free-floating balloons because they lacked engine power. Planes struggled to make headway into a stiff breeze, limiting their ability to choose where to fly. Hence, navigation was by using 'motor-car techniques'. Personal weather observations plus telegrams and the new fangled telephone were all used to gather pre-flight weather information. Then the aviators looked at maps, road signs and the names of railway stations and pubs!

In 1901, two years before the Wright brothers, J S Krauss raised the question 'how far is it possible?' in a publication entitled *Aerial Navigation: how far is it practicable?*, but by 1909, when Lawrence Rotch published *The Conquest of the Air, or the advent of aerial navigation*, the optimistic view was clearly that practical flying had arrived.

By 1911, Claude Grahame-White had established Hendon 'airport' in London; and on 9 September that year he initiated the first airmail service to the new King, George V, covering the 21 miles from Hendon to Windsor in ten minutes. Not until 1918 were regular mail services started in the USA. In 1920-21, the United States Post Office suffered 89 aircraft crashes and 19 pilots killed, the most common causes being adverse weather and mechanical failure. The 'Great War' delayed until 1919 the start of serious commercial flying in Europe.

FLYING IN EARNEST

WORLD WAR 1

Not surprisingly, the Great War led to dramatic advances in aviation, with increased use of aircraft of all sorts. Warfare became more critically dependent on the state of the atmosphere. The heightened profile of meteorology led the General Officer Commanding the Royal Flying Corps in the field to send a telegram to London on 5 May 1915, basically to ask for help in connection with aircraft work. At about the same time, the dangers of gas in particular prompted Major Foulkes at General Headquarters (GHQ) to seek the services of an expert meteorologist to be attached to give advice about wind direction (Minutes of the Proceedings of the Meteorological Committee, 1915-1916). The Director of the Meteorological Office, William Napier Shaw, negotiated with the War Office and by 10 June Major Lyons RE, FRS had proceeded to GHQ to represent him and get things organized. Two Meteorological Office staff had been released and granted commissions and were on their way to France. They were Captain E Gold and Lieutenant A E M Geddes. All this was set up in a little over one month.

The Meteorology Unit of the Royal Engineers was formally set up in September 1915, the functions of its staff being to:

- Act as Meteorological Advisers to the General Staff, both at General Headquarters and Army Headquarters.
- Supply all meteorological information required by the Royal Flying Corps (later the Royal Air Force).
- Furnish the regular reports required for the correction of range in Artillery operations.
- Furnish meteorological reports and forecasts for offensive and defensive gas operations.

"Operational" meteorology had begun.

Ernest Gold was the most notable meteorologist during World War 1. He was one of the first qualified scientists recruited to the Meteorological Office and a key figure in the development of international meteorological services for at least the next 30 years.

Pilots with a special interest in meteorology always did, and still do, want to understand the details, but in the early days, especially during World War 1, many pilots had minimal training and experience. For their convenience and as a brief résumé for others, the idea of 'fitness for flying' came into use as a function of wind, weather, cloud and visibility, and in some cases type of aircraft. After the War, Gold applied a scientific approach and presented a numerical index to the Third International Congress of Aerial Navigation (Gold, 1926). The concept of a 'fitness figure' was still widely used during the Second World War; and during the 1970s the concept was re-invented in the RAF as a 'colour state', summarising the operational status of an airfield. At times, it was a 'shorthand' for the weather at any place. Over the years, the popularity of the fitness index idea has varied considerably, and at different times both meteorologists and aviators in positions of influence have changed the policy. At a conference in 1919, for example, the representatives of the Society of British Aircraft Constructors were so strongly of the opinion that weather reports should contain no reference to fitness or unfitness for flying, even supplementing the detailed particulars of the different elements of the weather, that it was agreed to omit the estimate of fitness from official meteorological reports.

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THE START OF COMMERCIAL AVIATION – THE PIONEERS

With serviceable aircraft becoming surplus after the Armistice, the organization of airlines to operate these craft on a scheduled basis over regular routes was attempted. The first airline, the Deutsche Luftreederie was formed in Germany, and this began service from Berlin to Leipzig and Weimar on 5 February 1919. Only three days later, the French Farman Company began a cross-Channel service from Paris to London using a converted Farman F.60 Goliath bomber (Fig.3). In August 1919, the first daily service was established on this route from Le Bourget to Hounslow, with Croydon becoming the main airport by 1922. The oldest surviving airline, KLM, was formed in The Netherlands in 1919 and, jointly with a British company, began flying the Amsterdam-London route the following year. Outside Europe, the Queensland and Northern Territories Aerial Services Ltd (QANTAS) was founded in 1920. This eventually became the Australian national airline.

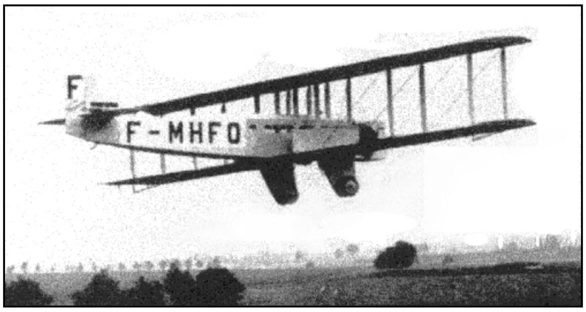


Figure 3
A Farman F.60 similar to the first cross-Channel airliner

THE ORGANIZATIONS

FOUNDATIONS

Understanding of the word 'aeronautical' has changed over the years. Late Victorian aeronautical societies were formed to promote the study of the atmosphere rather than the needs of aviation. Stemming from conferences of meteorologists in 1872 and 1873 (in Leipzig and Vienna, respectively), there developed the International Meteorological Organization (IMO), which formally came into being in 1879 at a meeting held in Rome. At this meeting, delegates decided that the IMO should comprise a Conference of Directors (the International Meteorological Committee) and various specialist Commissions. One of the latter, appointed in 1896, dealt with Scientific Aeronautics. Given the date, it is no surprise that research into the upper air was their prime concern, not aviation.

With the advent of fixed-wing flying in 1903, things began to change, although it was another five years before machines took to the air in Britain. Fearing that Britain might fail to experience the popular glory going to aviation, the government of the day formed an Advisory Committee for Aeronautics. An important step took place on 3 May 1909, when a memorandum of agreement was drawn up between the Aeronautical Society of Great Britain, the Aero Club and the Aerial League. They agreed to respect each others' activities and recognised the Aeronautical Society as the paramount scientific authority on aeronautical matters. Among its number was Dr W N Shaw, who was in charge of the Meteorological Office and keen to introduce both science and commercialism into meteorology. On 3 June 1909, he issued the Committee's first report on meteorology in the form of Memorandum No.9, which gave details of wind structure as well as vertical and rotary motion in the atmosphere (Advisory Committee for Aeronautics, 1909). All this came less than a year after the first official aeroplane flight in England. In the next ten years, members of the Aeronautical Committee, which included eminent scientists and engineers, issued many notes with titles like "Effect of wind on time of flight from one place to another" and "Effect of abnormal weather on aeroplane performance". These pioneering scientific and technical contributions laid the foundations for the advance of practicable, reliable navigation.

REGULATION IN THE UK

The Air Ministry was formed in January 1918 to cater for all aviation interests, following the Air Force (Constitution) Act of 1917. The Royal Air Force was officially formed on 1 April 1918 and First World War meteorological services for aviation were then re-organized. The Meteorological Office sent plans to the Ministry of Reconstruction (dated 20 November 1918) and memoranda to Lord Northcliffe's Committee on Commercial Aviation, the latter setting out arrangements for the supply of information to airmen. In addition, two special committees were formed by the Advisory Committee for Aeronautics: one regarding the protection of aircraft from lightning; the other concerning meteorology in general as applied to aeronautics.

It was announced in the House of Commons on 12 February 1919 that a Department of Civil Aviation would be formed under the Minister for Air; and by the end of the month, the Air Navigation Act had extended the scope of the Air Council to cover all matters concerned with air navigation. The conditions under which civil aviation might be carried out were set out in the Air Navigation Regulations of 1919, which were issued on 30 April. Thus, 'commercial civil aviation' in the UK may be deemed to have started on 1 May 1919.

In July 1919, the Controller General of Civil Aviation and representatives of the Air Ministry and the Meteorological Office proposed that the meteorological services of the Air Ministry should be co-ordinated with those of the Meteorological Office, the Meteorological Section of the Royal Engineers and the Meteorological Service of the Admiralty. One of the stated functions of the new body was to take care of all aspects of meteorology. The Director of the Meteorological Office was directly responsible to the Controller-General of Civil Aviation, albeit assisted by a meteorological committee. From 1 July 1919, the Meteorological Office formally became part of the new Air Ministry, combining the previously separate services run by the Office, the Air Ministry, the Royal Engineers and the Admiralty. Hence the new organization was directly involved with both the planning and implementation of official weather services for all aviators.

GOING INTERNATIONAL

Before World War 1, there was little commercial aviation; and during the conflict there was virtually none. After the Armistice, though, aviators and others realised that the developments in aviation which had taken place during the war would lead to commercial flying on an international scale. Vital to the pursuit of operational meteorology is active international co-operation, something that had been impracticable during the war. At an international meeting on 30 September 1919, Lieut-Col Matteuzzi proposed the nomination of a Meteorological Commission for Aerial Navigation "on which all nations should be represented" (Air Ministry - Meteorological Office, 1921). This sub-commission of the Peace Conference led to an International Air Convention, which was signed in Paris on 13 October 1919 (Air Ministry, 1919). Though not formally approved by the Supreme Council of the Peace Conference, this convention represents the real beginning of regulated international air navigation.

Article 35 stated that "There shall be instituted, under the name of the International Commission for Air Navigation and as part of the organization of the League of Nations, a permanent Commission composed of ...". It then listed the original representation. And Chapter II, Article 9, required regular contact with the International Commission for Air Navigation. In fact, two or three years were to elapse before ICAN became properly established, but some of the terminology in the seminal convention document is still recognisable in current ICAO publications.

Article 36 stated that "Each contracting State undertakes to co-operate as far as possible in international measures concerning the collection and dissemination of statistical, current, and special meteorological information, in accordance with the provisions of Annex G". From the meteorological point of view, Annex G set standards which have persisted into the current ICAO Annex 3 though revised and updated many times over the years. Annex E contained a list of the minimum qualifications necessary for obtaining certificates as pilots and navigators. Pilots had to know some "elementary meteorology", but navigators had to have "practical knowledge of meteorology and of weather charts". As a meteorologist, the author refrains from commenting on the difference!

At the meeting of the International Meteorological Committee at Utrecht in September 1923, the conference invited the President of the Commission for the Application of Meteorology to Aerial Navigation "to enter into relations with the International Commission for Air Navigation to obtain - if possible - all the resolutions of the sub-commission for Meteorology, and to communicate them to the meteorological services of those nations which have not yet joined the ICAN". This was the real start of the close co-operation between the two organizations responsible for meteorology and commercial flying (Koninklijk Nederlands Meteorologisch Instituut, 1924).

In the 1930s, Meteorological Office Annual Reports (for years ending 31 March) noted the continuing expansion of services required by commercial aviation (Director of the Meteorological Office, 1931-38). In 1931, services based at Croydon were extended to 24 hours for continental flights and an experimental service started from Croydon to Liverpool (extended to much of the British Isles by 1934-5). It is interesting to see that from 1 November 1932 reports and forecasts displayed at Croydon and Lympne were using metric units for wind, heights and visibility. By 1933, there was a regular night service from Croydon to Berlin in the summer; and in October and March 120 successful candidates were examined in Meteorology for their 2nd Class Navigator licences. Written examination of aircrew was supplemented by individual interviews until soon after World War 2, when the number of candidates increased dramatically and interviewing ceased. In the 1980s, multiple-choice questions set and marked by meteorologists were introduced to replace the examinations.

In the 1930s, special arrangements were made to provide meteorological services for King's Cup Air Races, the Imperial Airways Cape-Cairo service, the projected trans-Atlantic service of the Graf Zeppelin and flights by individual pioneers such as Amy Johnson, Alan Cobham and James Mollison.

In the late 1930s, new technology provided a searchlight to measure cloud base at night, and problems of ice accretion received special attention. Whether as a result of technological advances or the political situation, a flurry of meetings took place in 1937: the IMO Commission on Aeronautical Meteorology met in Paris in May; the International Meteorological Committee convened in Salzburg in June; and the Meteorological Sub-committee of ICAN met in Paris in September. There followed an International Aeronautical Conference in Paris in 1938. Although the normal run of international conferences ceased during World War 2, there were some meetings in Switzerland on "Protection météorologique internationale de l'aeronautique".

Clearly, matters were becoming better organized by the late 1930s, when *Meteorology for Aviators* was published (Air Ministry, 1939). In this book, the author, Dr R C Sutcliffe, stated: "To serve as an illustration of the sort of organization available, an outline of the arrangements made within the British

Isles and the neighbouring continent will now be given; this may be taken as a model of organizations elsewhere, although detail must differ according to local requirements".

He went on to note that the various parts of the organization were:
- The establishment of a network of observing stations.
- Unification of methods of observation, elements to be observed, and the times at which observations should be made.
- Unification of the system of reporting, using international codes for the sake of brevity and to overcome language difficulties.
- Systems of communication allowing the reports to be placed in the hands of all forecasting services with the least possible delay.
- Uniform methods of representing the information received on charts or weather maps, so that they may be understood, independently of nationality, by any trained pilot.
- Arrangements for broadcasting information for the use of aviators in general.
- Arrangements for supplying special information, by request, to pilots on the ground or in the air.

Sutcliffe also made it clear that the book "covered the present syllabuses for the First and Second Class Civil Air Navigators' Licences and the parallel training courses of the Royal Air Force."

THE OPERATIONAL FRAMEWORK

Creation of a meteorological service for the aviation industry clearly required innovative action and this was recorded in detail in the Annual Reports of the Meteorological Committee. Although rather long, these reports catalogue the great effort put into developing the new service.

For the year ending March 1920, there is a Report by Lieut-Col E Gold CB DSO FRS (Fig.4), repatriated and by then Assistant Director of the Meteorological Office (Meteorological Committee, 1920). He explained that by the close of the financial year 1918-19, most of the special war demands upon the Forecast Service had ceased and the process of post-war development had begun. The requirements of the Armies of Occupation and of the Expeditionary Forces to North Russia made demands upon the Forecast Service until October 1919 and data were supplied regularly to the Meteorological Sections of the Royal Engineers at Cologne, Wimereux, Murmansk and Archangel.

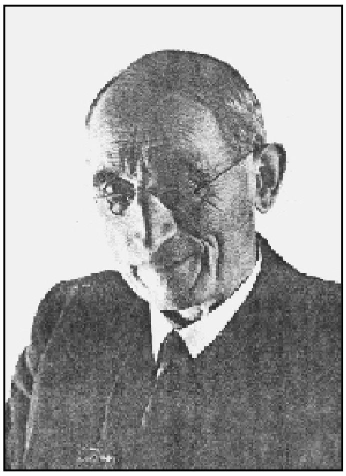


Figure 4
Mr E Gold, CB, DSO, FRS

BASIC DATA

Surface observations were received in 1919 from existing telegraphic reporting stations plus the following new stations of the Forecast Service: Calshot, Croydon, Biggin Hill, Beachy Head, Lympne, Felixstowe, Cranwell, Howden and Baldonnel.

The resumption of international co-operation encouraged the development of the use of wireless telegraphy for the transmission of synoptic data between different countries. Such messages were sent out daily from the following European countries by the close of the year: Belgium, Great Britain, Czecho-Slovakia, Holland, Denmark, Italy, Estonia, Poland, France, Spain, Germany and Sweden. Considerable difficulties still arose in this method of transmission. Synoptic data of a quality that compared at all favourably, in practical utility, with transmission by cable were received in London from only two or three countries with sufficient regularity.

As regards the supply of data from Great Britain to countries abroad, W/T messages were transmitted from various stations, and messages by cable were transmitted to the following countries: Denmark, Norway, France, Sweden, Holland, Switzerland, Italy.

During the summer of 1919, when trans-Atlantic aviation made considerable demands upon national meteorological services, numerous observations from ships at sea were received by W/T and charted.

DISTRIBUTIVE STATIONS

A major advance in the organization of meteorological services was the concept of a network of Local Meteorological Centres, which commenced on 10 November 1919, at which time the intention was that the final number of such centres would be twenty. The plan was that each centre would be staffed by a professional meteorologist, assisted by trained technical staff. The duties of the staff were stated as:

- To make all necessary local observations, especially of upper wind, visibility and cloud.
- To collect simple meteorological reports from other places in the area.
- To receive by wireless telegraphy or by ordinary telegram the necessary collective reports for the preparation of synoptic charts.
- To advise especially the aviation services in the area and generally to supply expert meteorological information and advice for all services.

As it would take time to provide trained staff at all planned stations, the decision was made that priority would be given to the most urgent needs of the situation, i.e. the provision of adequate reports and forecasts for the London-Paris-Brussels aerial routes.

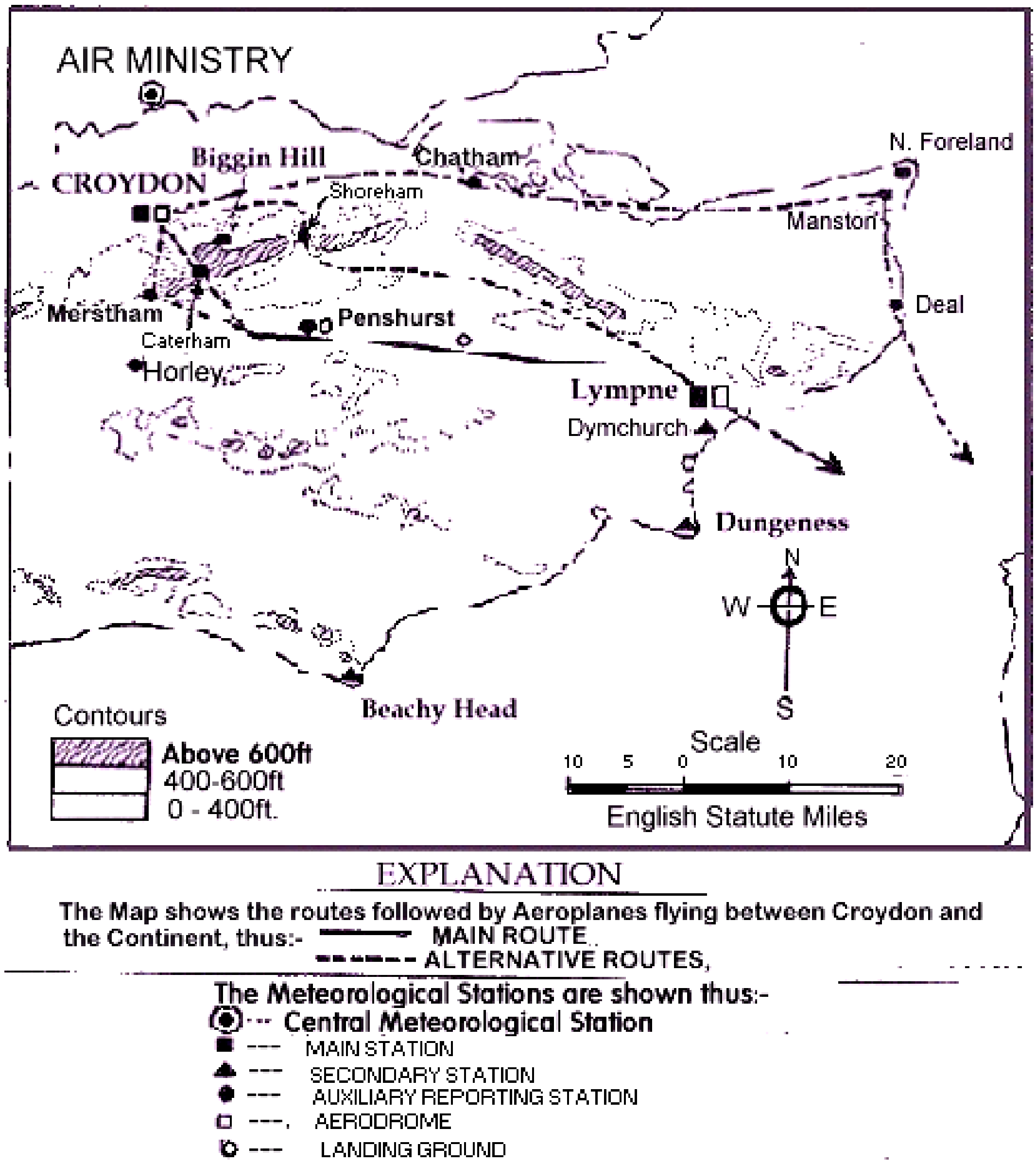


Figure 5
Air routes to the continent

INFORMATION FOR AVIATORS

INITIAL ARRANGEMENTS 1919-20

On 25 November 1919, at a conference attended by representatives of the Society of British Aircraft Constructors, proposals were made, and agreement was reached, regarding the nature of the reports which the Meteorological Office should supply in connection with commercial aerial routes. The basic information required from points along each route was considered to be:

- Wind at surface and at 2,000 feet.
- Weather (present and past) in general terms.
- Amount and height of any low cloud.
- Visibility.
- (For seaplanes) The state of the sea, particularly in regard to the nature and amount of the swell, which greatly affected the power of the machine to rise from the water.

The code for exchanging data was a slightly modified form of the code for abbreviated reports given in Annex G (Appendix IV) of the Convention relating to International Air Navigation, Paris, 1919; it was adopted as providing for existing national and international requirements. At the conference on 25 November 1919, participants further agreed that information given by wireless telephone to machines in the air should be in plain language and not in code.

From 22 November 1919, an acting Assistant Superintendent took charge of the preparation and issue of reports in connection with flying in south-east England. At the end of the month, arrangements were completed for opening the first Distributive Centre at Hounslow Aerodrome and for the interchange of information with the Central Office. On 1 December, work commenced with one Professional and one Technical Assistant. Reports, in so far as they were available, were received there hourly from 7.30 am to 2.30 pm, and forecasts for the London-Paris-Brussels routes, prepared at the Central Office, were transmitted to Hounslow at about 9.30 am and 2.30 pm daily. Reports of conditions in south-east England were also prepared and transmitted by wireless to Paris hourly from 07:45 to 14:45 daily. These became gradually more complete as stations were opened, and from 20 February were sent in the recently agreed coded form. The importance of the route to Paris was, of course, that it was used for the transportation of officials and diplomats attending peace negotiations. The other important route from March to August 1919 was the mail run to Cologne for the Army of Occupation. Reputedly, Acting-Major Herbert Gardner Travers was in February 1919 "transferred to GHQ St. André as Navigating Officer I/C Postal Squadrons, and in that capacity soon arranged for weather stations to be set up *en route* between Folkestone and Cologne" (Travers, 1990), but no indication is given of the resources used. One assumes he made representation to the new Air Ministry. The significant point is that a pioneering aerial navigation specialist recognized the need for up-to-date weather information.

Certain additional information was also issued from the Central Office. From 3 December, a statement was prepared for the press each evening on the weather prospects for the following day on these routes (see Fig.5). From 11 December, the new "B B" report was issued daily at 9.30 am, together with a forecast for the ensuing period of daylight, and the "C" report was supplemented by a similar statement. In the preparation of these reports, the lack of definite and suitable information along the routes was much felt, and the information from the French authorities in particular was irregular in arrival and defective in detail and frequency. The occurrence of a flying accident at Caterham on 11 December emphasised the recognised need for a reporting station on the North Downs, as difficulty was frequently experienced there by pilots on account of low cloud.

It was reported that:

> "Special attention has been given to the London-Paris route and a service of weather reports along this route has been maintained. It was not possible to make as complete arrangements as desired; especially in France, but the reports of the weather at other stations on the route in terms of a 'Weather Fitness Scale' were sent to each control station every hour from 07:00-19:00 (7.00 am to 7.00 pm) throughout the six months. An officer and one man were stationed at Buc to receive and distribute the information sent each hour from this section."

This officer was also supplied with the necessary apparatus for determining wind speed and direction at various altitudes.

To enable conditions over the country to be readily understood by applicants for information, a system of pin discs and maps was devised and exhibited in the Air Ministry; and at aerodromes symbols were placed on the ground to be visible from the air (Fig.6).

Figure 6
Messages for pilots without radio

Further staff having become available, it was possible to open a station at Lympne Aerodrome (on similar lines to that at Hounslow) on 14 January 1920 and a subsidiary station with only a single observer at Biggin Hill on 17 February. The former station, in addition to normal reports, supplied meteorological information in connection with the experimental work carried out at the Small Arms School, Hythe, Kent. A point of interest is that information could be supplied from this station to machines in the air by wireless telephone, though few machines were suitably equipped. Arrangements had been made with the Admiral Commanding Coastguards and Reserves for the Coastguard Station at Beachy Head to act as a telegraphic reporting station, with a view to improving weather reports for Cross-Channel flying. These arrangements came into operation from 2 February.

Arrangements for reporting weather in south-east England were now from the flying point of view reasonably satisfactory, and steps were next taken to secure improvements in reporting from France. On 15 March, Captain Gain of the Service Météorologique de la Navigation Aérienne and Captain Franck of the French Wireless Service visited the Air Ministry. An informal conference took place between the British and French meteorological and wireless representatives, as a result of which it was decided that certain hourly observations should be made at several stations in each country. It was agreed that these should be transmitted by the French at 30 minutes past the hour and by the British at 35 minutes past the hour, and also that the arrangement should take effect from 13 April 1920. It was agreed, too, that the Belgians be asked to fall into line with this arrangement and to transmit at 25 minutes past the hour. Reports from Brussels along these lines commenced on 22 April.

On 28 March, the terminal aerodrome on the British side of the Channel was transferred from Hounslow to Croydon and the meteorological station moved on the same day.

SPECIAL REPORTS

In addition to the routine work described above, special cases for advice or consideration had arisen from time to time. Synoptic data and forecasts had been supplied daily from Headquarters to the meteorological representative of the Aircraft Transport and Travel Company. Reports were also prepared for the information of the Accidents Investigation Branch of the Air Ministry in connection with reported accidents to aircraft. Concurrently, with the development of local centres in south-east England, arrangements were proceeding for the establishment of stations in other districts. The stations, which it was intended eventually to establish, were arranged in a provisional order of priority according to the urgency of their various requirements.

METEOROLOGICAL SECTION, RAF, APRIL-SEPTEMBER, 1919

Immediately after the Great War, virtually all experienced aviators were in, or had recently left, the Services. Much serious flying during this seminal period took place under the auspices of the Air Ministry and hence the RAF. Squadron-Leader Gendle OBE was the linking figure at the time and he reported (Meteorological Committee, 1920) that, during the first ten months after the Armistice, this section had had to face "increasing demands for weather forecasts in connection with Cross-Atlantic Flights, Aerial Routes and Demonstration Flights, with a continual decrease in the personnel". He was not happy with more extensive work and fewer resources but still boasted that:

> "The weather maps have been drawn up at six-hour intervals from information supplied by a network of stations of the Royal Air Force and Meteorological Office. Reports and forecasts covering various aerial routes have been prepared and issued, together with maps showing the speed and direction of the upper wind over the country, to heads of departments in the Air Ministry and pilots of machines undertaking flights to and from various parts of the United Kingdom."

Special Reports were issued for a variety of flights and exhibitions, extending to such places as Amsterdam, Madrid, Egypt, Scandinavia and Rome. Various conferences were held to consider the aerial routes from London to Paris, England to Australia and Cairo to Karachi; and research and statistical work was carried out at the request of the Controller General of Civil Aviation.

TRANS-ATLANTIC FLIGHTS

For the competition organized by The Daily Mail to encourage trans-Atlantic flights, necessary meteorological arrangements were made to ensure that competitors received all information available. Meteorological officers and men were sent to St John's, Newfoundland, the Azores and Lisbon, together with sufficient equipment to enable observations of the upper air and general weather conditions to be obtained. In addition, the Portuguese Government was approached and gave all assistance possible. With the co-operation of the Controller of Communications, very complete arrangements were made for the collection and transmission of the weather reports of the United States to St John's, Newfoundland, and to the Air Ministry. The United States gave every facility in obtaining a rapid system of weather reporting from America, and took steps to ensure that the system was maintained and improved as occasion demanded. Further arrangements were made with the Marconi Company for the transmission of synoptic weather reports from the British Isles by wireless from Carnarvon and for weather reports by wireless from ships at sea. The ships' reports, when received regularly, were of great assistance in drawing synoptic charts of the Atlantic. The flight was accomplished by Capt John Alcock and Lieut Arthur Whitten Brown on 14-15 June, 1919 (Fig.7).

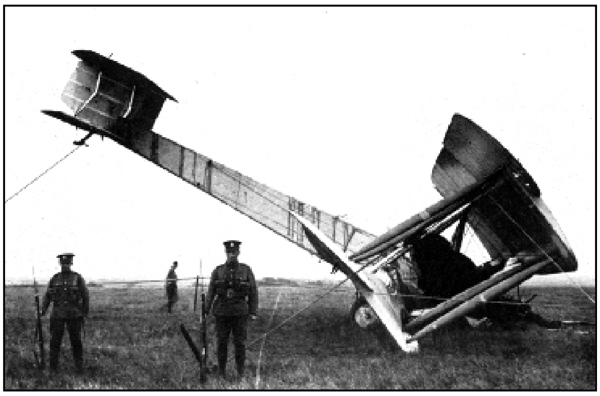


Figure 7
The Vickers Vimy that crossed the Atlantic in June 1919

Reports by radio from Atlantic liners were initiated in 1909 but ceased during the war. They were restored temporarily by the Meteorological Service of the Air Ministry in connection with 1919 trans-Atlantic flights and later reinstated on a permanent basis by a new co-ordinated service.

GOING GLOBAL

AIRSHIPS

Before the 'war to end all wars' (sic), German Zeppelins had demonstrated the feasibility of regular passenger-carrying flights. After the war, many thought that aeroplanes would never replace ocean liners but that large airships might take over on the long inter-continental routes, especially those linking the British Empire. An early project of the new Air Ministry was to set objectives for the flight in July 1919 of the R.34 airship: firstly, the acquisition of information and data concerning conditions over the Atlantic during extended flight – not only from the point of view of the airship pilot but also from the point of view of the meteorologist; secondly, to demonstrate the possibilities of large rigid airships with regard to carrying out long overseas voyages (a cynic may wonder if there wasn't an element of showing off to the Americans as well).

In accordance with a special request from the Deputy Chief of the Air Staff, an officer from FO.5. was sent on R.34 (Fig.8). Lieut Guy Harris was the meteorologist in the ship's company when at 1.42 am on 2 July 1919 the bugle sounded 'let go' at East Fortune near Edinburgh and the journey began. The consensus view of those on the flight was that large rigid airships would be much steadier over the sea than surface ships and much safer from the dangers of icebergs (a serious consideration at the time, given that the Titanic disaster had occurred only seven years earlier). The flight of R.34 in 1919 also demonstrated the potential benefits of wireless for gathering weather reports, determining directional bearings and obtaining navigational fixes (Abbott, 1994). The need for meteorological data to be gathered routinely from over the oceans was also recognised, with the data supplied perhaps from cable repair ships, as these were widely scattered but tended to remain in one spot for a relatively long time. The expectation was that "the captains of the future Airship Liners will become wily and cunning masters of the art of selecting the right wind and the right height, and, by means of their air knowledge alone will save many hours … on passage".

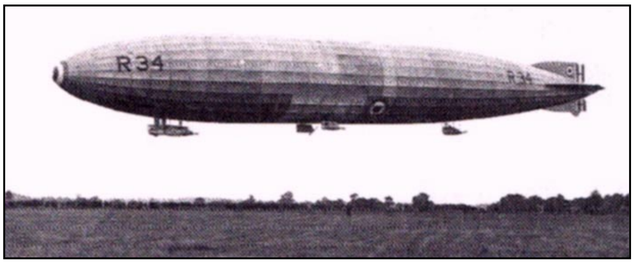


Figure 8
The R.34 after the first successful two-way crossing of the Atlantic

For the flight of R.34, arrangements similar to those for Alcock and Brown were made, with two meteorological officers sent out on each of the battle cruisers *Tiger* and *Renown*. These ships were stationed north and south of the usual Atlantic steamship line, and the observations sent by them were of great assistance in drawing up weather maps of the Atlantic. The observations were of considerable value as a check on reports from merchant ships.

During the flights (July 2-6, and 10-13), small synoptic maps of the Atlantic were prepared in London and distributed to the heads of all departments in the Air Ministry, together with complete reports and forecasts, which were also issued to the Press. A detailed account of arrangements for trans-Atlantic flights was prepared by Sqn-Ldr Gendle in December 1919 and passed to Dr W N (now Sir Napier) Shaw. He finished by saying:

> "Finally, any organization that is set up for future flights must be clearly established both technically and financially and not dependent only on the kindness and goodwill of those concerned. In other words, the Governments on both sides of the Atlantic must be prepared to meet very considerable expenditure. Any organization set up for Atlantic flights will be a great help to weather forecasting for the British Isles. It was found that the period for which weather forecasts could be given in this country was more than doubled."

Gendle had a clear idea of how arrangements should proceed but it was nearly thirty years before it became a reality.

In spite of the success of the R.34, the Air Ministry issued an Order in September 1920 decreeing that all airship work should cease. The Ministry suddenly decided that airship travel was not economic, so by the autumn of 1921 there were a few airships in store but most had been broken up. In 1922, however, Vickers proposed a fleet of six civil airships rather like the proven Zeppelins, to circumnavigate the globe and "to link the Empire".

One of the unknowns was how to provide weather information on such an ambitious scale. Meteorologists needed to work out how to forecast the weather over these extended distances and provide data so that in-flight decisions could be made. To meet these needs, the Airship Division of the Meteorological Office was formed, and this existed from January 1925 to the end of 1931, carrying out original and important investigative work, in particular about the structure of low-level winds. In charge of the Division was a very competent scientist called Maurice Giblett, who had served as Deputy in charge of the Forecast Division soon after joining the Meteorological Office. The Airship Division built a meteorological facility at Cardington, which by March 1926 was the primary centre for research and the development of services for airships. The facility was actually mounted on a tower which had a radio aerial and an anemometer on top of the tower at a reasonable height for the airships that were parked 'just down the road' at a similar height.

To study the problems of world-wide flying, Giblett undertook a world tour and investigated places where airships might conveniently be used. The outcome was an ambitious one: that routes were planned from the UK to Canada, South Africa, India, Australia and New Zealand (see Fig.9). The meteorological organization set up to cope with flights to the east had centres at Cardington, Ismalia and Karachi, which were both airship bases and meteorological centres. To relay data, radio facilities at various intermediate places were employed.

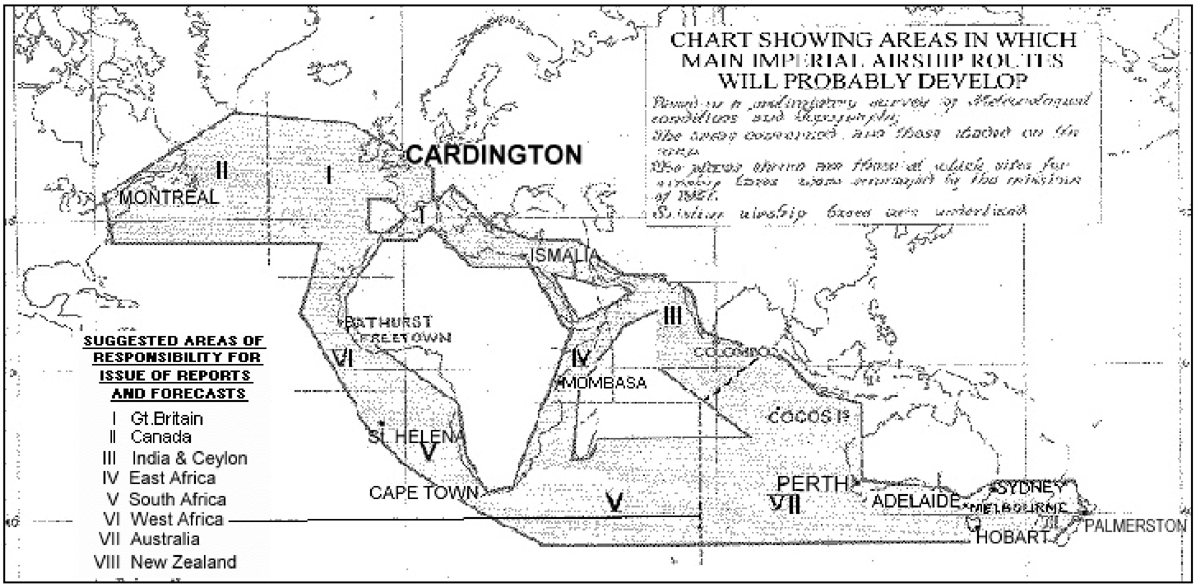


Figure 9
Chart showing planned coverage for Empire airship routes

One of the first things Giblett's group decided to do was, in fact, to analyse a retrospective series of charts, so that they could actually study the weather over such a large area. They decided to analyse a whole year beginning on 1 April 1924, an exercise that helped show which data were needed for operational flying. The charts for this work were newly available, covering a greater area than any before. Form 2206 was entitled 'England-Egypt-India airship route working chart' and a version was produced with all the key observing stations named and squares marked out to make it easy to cut into fifteen sheets. It was, therefore, a practical tool for use over any part of the route.

Giblett's group decided that data would be transmitted to airships in flight by radio. Indeed, they decided not only to use radio telegraphy and telephony but also to try and send pictures and words by radio. On 20 March 1929, a photograph transmitter was attached to the R/T transmitter at Cardington and charts and forecasts were broadcast via the mast at Daventry. They were sent by means of the so-called Fultograph System (a facility unfamiliar to most people until at least the 1950s), and they were received live at a Royal Meteorological Society meeting during a talk by R A Watson-Watt on the uses of radio in relation to meteorology (Fig.10, p.14). At the time, Watson-Watt was Superintendent of the Department of Scientific and Industrial Research's Radio Research Station at Slough.

The R.101 was scheduled to take off on a flight to India on 4 October 1930 and, against the better judgement of some, actually left that day in deteriorating weather. Soon afterwards, at nine minutes past two on the morning of 5 October, it crashed near Beauvais in France. A former member of the Airship Division at Cardington told me that he was speaking to the Superintendent, Maurice Giblett, on the evening before they took off and Giblett was most apprehensive about the decision to leave at that time. He was obviously justified; and he was among those who lost their lives. The ill-fated flight of the R.101 was one of the worst-ever cases of that curse of some aviators known as 'press-on-itis'.

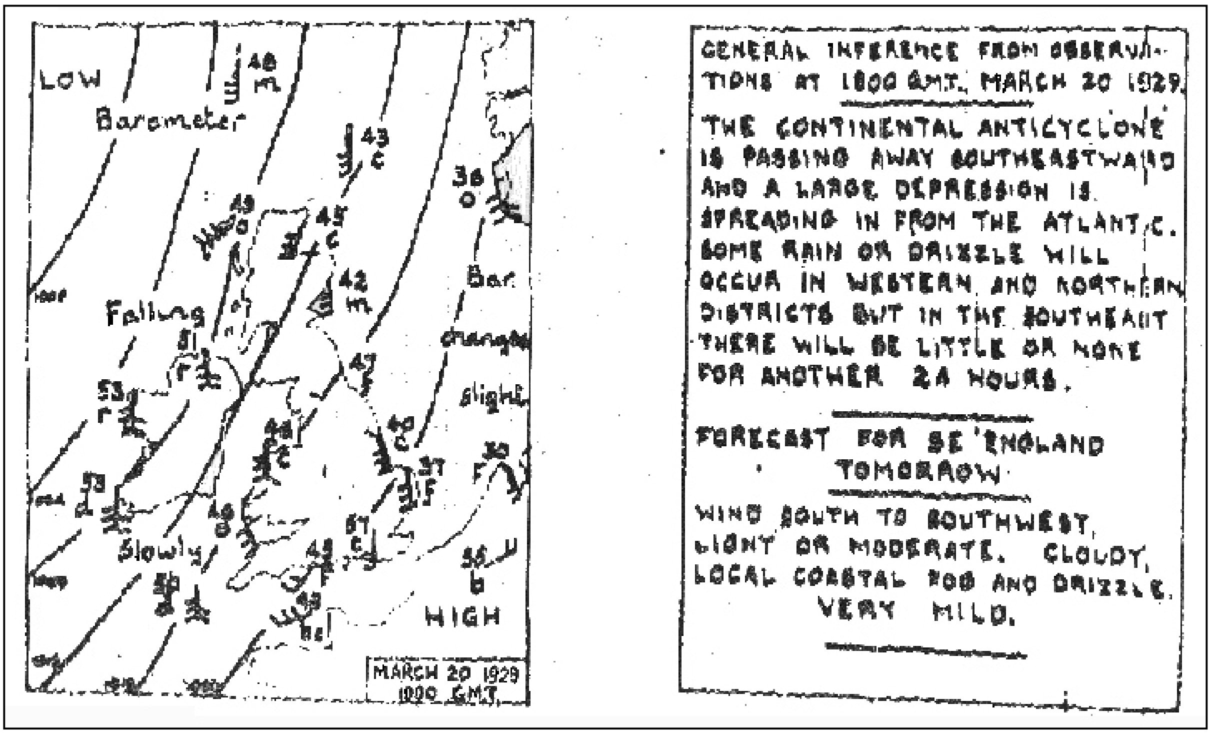


Figure 10
Sample chart and forecast sent by radio

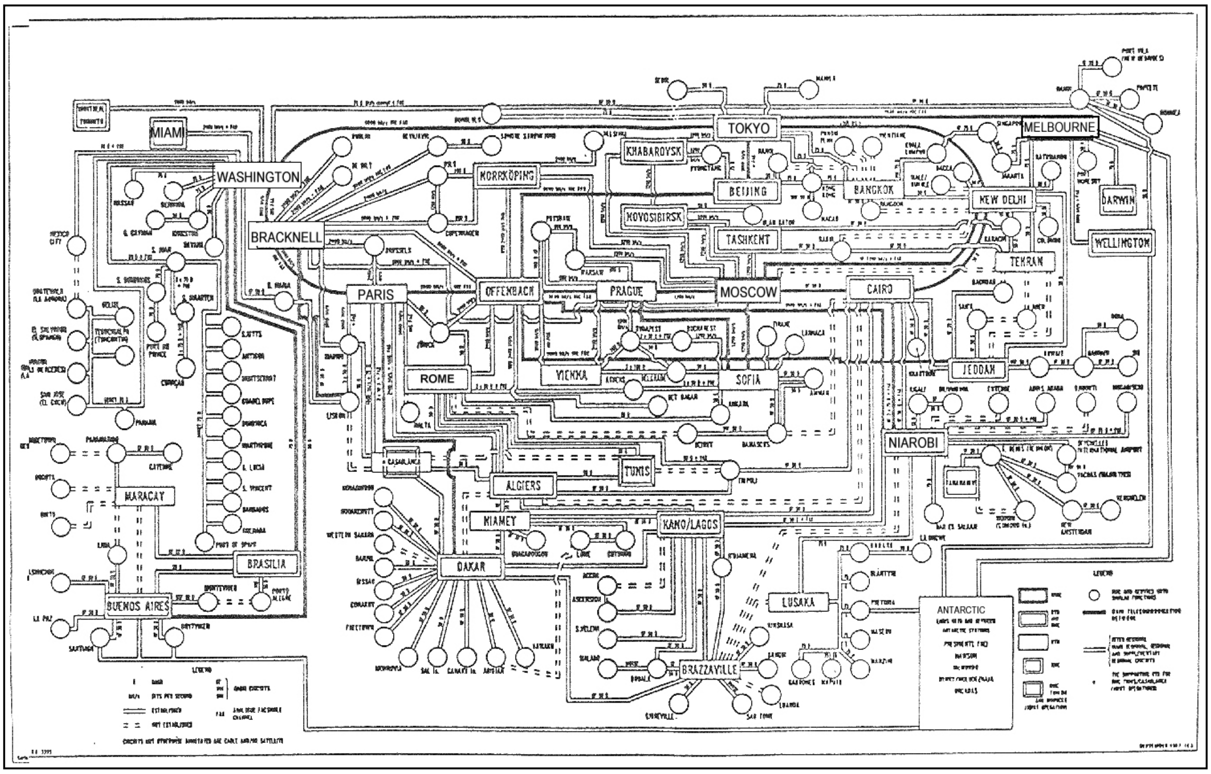


Figure 11
Plan of the Global Telecommunication System

COMMUNICATIONS

Communications are the key to scientific meteorology, especially when such matters as safety of international flights are concerned.

CABLES

It was the introduction of the electric telegraph in the middle of the 19th century that transformed meteorology from an academic pursuit into a practical science, but it depended, of course, on cables. By the early 20th century, full advantage had been taken of the telegraph, telegrams and the telephone, using cable and depending on intermediaries to bring about the transmission of information to users. In 1907, the International Meteorological Committee established a Commission for Weather Telegraphy, having become aware of the services being introduced by the Marconi Wireless Telegraph Company. Over the next few years, radio telegraphy was used increasingly as the technology improved. Most notably, ship to shore communications offered the meteorologist a major new source of vital data, and international messages could be delivered more promptly. Not surprisingly, the level of real international co-operation was disrupted during the 1914-18 war, although the technology and techniques improved. Cable systems grew until the late 20th century, when the World Meteorological Organization organised a global trunk circuit (Fig.11) that connected most of the countries in the world. Fig.12 shows part of the system in greater detail.

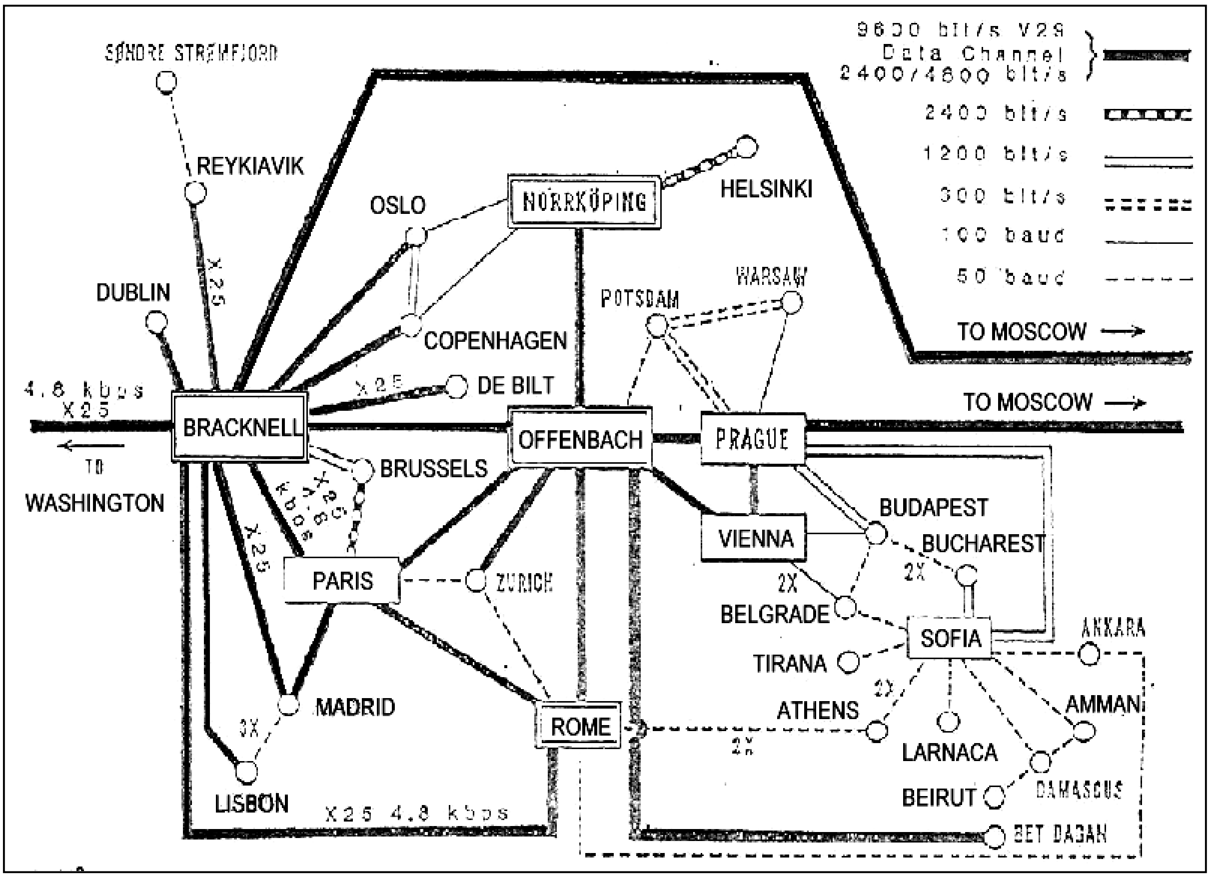


Figure 12
Part of the Global Trunk Circuit

WIRELESS

The crew on the flight of the R.34 across the Atlantic and back in 1919 saw the great potential of radio for direction finding and supplying weather data to fliers over long distances, even if the quality of reception was a bit hit and miss at that time. Nevertheless, during the 1920s and '30s radio telegraphy came to play a vital part in the expanding worlds of both aviation and meteorology.

By 1935, it had become obvious that radio telegraphic communications systems could not fully cope with the increased demand for information. It was also clear that radio was potentially vulnerable to security breaches in times of conflict. By November 1937, the basis of a dedicated national teleprinter landline network was in place, and in 1938 twenty stations were connected. By the start of World War 2, the number of stations had increased to 48. By the end of the War, there were 552 recipients of the main channel broadcast from the Meteorological Office headquarters at Dunstable. Under the auspices of the World Meteorological Organization, most countries in the world were linked to a global teleprinter system during the late 20th century, creating the largest dedicated communications network seen up that time, one that combined cable with radio links. Then, further advances in communications technology, this time using electronic computers, brought new opportunities for rapid transmission of meteorological information and data, making possible volumes and speed of message traffic that our forebears would have considered unbelievable. The Internet and the World Wide Web have brought yet another dimension, which at the beginning of the 21st century promises more than most humans can comprehend.

AIRMET, VOLMET

By 1931, it had been recognised that the needs of 'owner pilots' were not satisfactorily met. In 1932, the Air Ministry (Meteorological Office), Automobile Association (Aviation Branch) and the General Post Office (licensing authority) co-operated to start broadcasting from Heston. Reports were decoded and transmitted in plain language by radio telephony so that anyone with access to a wireless receiver (radio) could hear the information from aerodromes within about 200 miles of Heston. Light, portable receivers were being fitted to aircraft by this time, allowing reception in-flight. On 10 July 1935, the Meteorological Office took over the service from the AA and the scope was increased by transmitting from the wireless station at Borough Hill, Northamptonshire, using the wavelength 1186 metres (253 kHz). Weather reports, forecasts and navigational warnings could be heard over a large part of the British Isles and near continent, with an almost continuous service from 7 am to 8 pm, varying between summer and winter. By 1938, an increasing amount of information was broadcast and the service re-organized when the Headquarters moved from Adastral House to more-spacious quarters in Victory House.

Not surprisingly, this service was suspended during World War 2, but the Meteorological Office Director's first post-war Annual Report (Director of the Meteorological Office (1947) tells us that "AIRMET broadcasts, which are similar to the Borough Hill weather broadcasts of pre-war days, were begun on January 7, 1946". The service transmitted on 1224 metres (245 kHz) was seen by R M Poulter as providing "a very useful up-to-the-minute weather service for anyone interested in flying or other outdoor activity" (Poulter, 1946).

The service proved popular with a very wide variety of users, but there not enough of them. The Government signed up to the Copenhagen Broadcasting Plan, which set about the re-allocation of radio frequency/wavelength channels and Airmet ceased in March 1950. The promised alternative frequency never materialised, in spite of a 21,400-signature petition organized by the editors of the Royal Meteorological Society's *Weather* magazine, with logical arguments about both safety and economics from eminent users. In June 1952, *Weather* reported (p.189) that "In the House of Commons on 8 May the Under Secretary of State for Air, replying to a question by Sir Ian Frazer, M.P., stated that there was still no prospect of a suitable frequency being made available for Airmet".

By the late 1950s, the Civil Aviation Authority had started broadcasting plain-language information on dedicated VHF frequencies with a call-sign VOLMET. One of the author's first jobs as a National Service Meteorological Airman at RAF Uxbridge (near Southern Air Traffic Control Centre) was filling in a QAM sheet with decoded weather observations and sending them off in a Lamsden tube for general dissemination. Over the years, the system became more and more automated until it is now possible for an automatic weather station to send its data to another computer that converts the information to plain language that is broadcast all untouched by human hand or mispronounced by live voice.

RISING TO NEW HEIGHTS

UPPER AIR - THE THIRD DIMENSION

With the cessation of hostilities at the close of 1918 and the gradual demobilization of the meteorological personnel of the Army and Royal Air Force, considerably less information concerning upper winds was available during 1919 than during 1918, but reports continued to be received from the observatories of the Meteorological Office and from certain stations of the Royal Air Force. Upper-wind reports using pilot balloons commenced at the newly-established stations of the Forecast Service. Since the 18th century, many pioneers had studied the upper air using kites and occasionally balloons, but it was not until the early 20th century that reliable instruments and balloons were available for frequent or regular ascents, initially on tethered balloons or kites. A major problem remained over the need to recover meteorographs launched on free-flying balloons. The meteorology/aviation relationship was an interactive exercise with a more scientific approach to meteorology providing more services and some of the flyers using their machines to study the weather.

The best example of such people was C K M Douglas (ex-Capt RFC), who produced a pioneering paper on the uses of aeroplanes in the study of meteorology. There followed experimental flights in 1918/19 under the auspices of E Gold. After the conflict, Douglas became one of the best practical meteorologists in England and the senior forecaster during World War 2 (Fig.13). It was reported in 1920 (Meteorological Committee, 1920) that "Arrangements were made with the Royal Air Force for four Service pilots and machines to be detailed specially for meteorological work". It was recognised that upper-air information was vital to meteorological work and that there was an increasing demand for aircraft to operate out of sight of land and/or above cloud. By the 1930s, a special flight was based at Duxford for upper-air work. After the war, THUM (Thermal Upper-Air Measurement) and PRATA (Pressure and Temperature Sounding) flights from Worcester continued to record temperature and humidity in the upper atmosphere until the late 1950s. Meteorological reconnaissance flying expanded considerably during World War 2, with routine flights continuing until the 1960s, when the flights code-named BISMUTH over the Atlantic from Aldergrove were discontinued. Research flying still continues, but aircraft are now rarely used for routine upper-air observations. In the 1930s, technical aids to navigation were in their infancy but, nevertheless, developing and leading to an increased need for wind, temperature and weather forecasts. These were necessary to allow aviators to compensate for nature's imposed deviations from straightforward compass and map following. Airlines needed to plan fuel and payloads accurately.

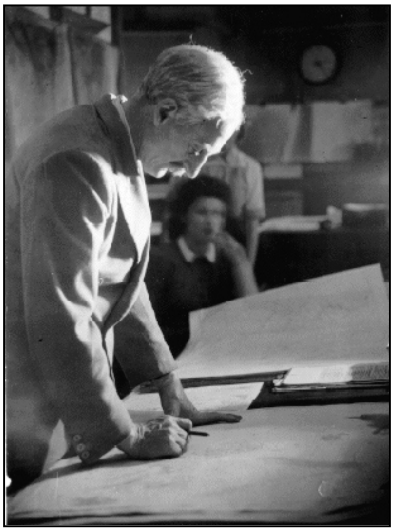


Figure 13
C K M Douglas, OBE, AFC, MA

OBSERVING

In the 19th century and early part of the 20th, a lot of work was devoted to detailed observation and classification of clouds, with attempts to measure both height and horizontal movement of clouds, from which upper winds could be deduced. Thus, ideas began to form about processes and dynamics of the upper air. Early observations made by pioneers in free-floating balloons provided rare and rather haphazard information about the upper air, but towards the end of the 19th century pioneers in several countries began to use small 'pilot balloons', which were registered balloons with post cards attached. Increasingly, kites with attached self-recording meteorographs were deployed, the main deficiencies of these instruments being that they had to be retrieved and interpreted. They were valuable for research and working out average conditions but slow for operational needs. Aeroplanes had promise but were expensive and weather-dependent. The breakthrough came with the use of radio-sounding techniques to probe the atmosphere, using miniaturised, disposable equipment. After the first successful attempt in France in 1927, other countries gradually developed their own instruments, allowing upper-air networks to be introduced in the late 1930s. Such networks became widely established during the Second World War to meet the demands of aviators flying faster and higher than ever before. Thus, meteorologists increased their knowledge of the upper air and its relationship to weather.

The major advances in the latter half of the 20th century were probably radar and satellite imagery, both of which extended the coverage that previously depended on visual observations. The ability to see the distribution and often intensity of precipitation and cloud, especially over areas lacking conventional observations, transformed weather analysis and forecasting.

Developments in electronics have brought about major changes in the day-to-day work of weather observers, with remote sensing and recording reducing the need to read every instrument.

FORECASTING

Major steps in the evolution of scientific weather forecasting appeared over many years. As mentioned earlier, the electric telegraph made possible for the first time the collection of near real-time data from a relatively large geographical area. This also made possible the drawing of a synoptic chart for 'today' in (almost) real time, which led, in turn, to the first attempts being made to assess the chart for tomorrow. Towards the end of the 19th century, a start was made on measuring the upper air and pioneers attempted to think about the three- (four-) dimensional atmosphere.

A significant advance was made by Ernest Gold in 1908, when he published a report on the calculation of wind velocity from pressure distribution (Gold, 1908). Making use of theoretical equations produced by earlier scientists, he compared actual meteorological data with practical chart measurements, taking account of the curvature of the air's track and the earth. He thus paved the way for forecasters to provide winds for navigation when aviators became rash enough to fly above cloud.

Shortly after the First World War, the team of meteorologists in Bergen led by Vilhelm and Jacob Bjerknes put forward their three-dimensional models of air masses and fronts, but it was not until the 1940s and '50s that technology became sophisticated enough to provide the routine upper-air data needed to validate and apply the ideas.

In 1922, the mathematician and meteorologist L F Richardson proposed the idea of numerical weather forecasting but his techniques had to await the arrival of powerful-enough electronic computers. During World War 2, the availability of routine upper-air data and the demands of aviators flying higher and further led to the Meteorological Office creating an upper-air section at Dunstable. Under Sverre Petterssen, a pioneer from the Norwegian school, this unit developed ways to chart the atmosphere in three dimensions. One such technique, called 'gridding', allowed forecasters to develop a scientifically-sound method of relating different layers in the upper air. Greater consistency was possibly during both analysis of actual data and the creation of forecast charts, especially when R C Sutcliffe's development theory was applied to synoptic charts. The previously mentioned advances in observing in the second half of the 20th century contributed greatly to improved weather forecasting.

CALCULATED NAVIGATION

At some stage, a mathematically-inclined aviator who used his eyes when flying must have thought about the relationship between track, heading and wind. As a meteorologist, Ernest Gold realised the importance of applying a scientific approach and included the basic mathematics in a pioneering article in 1919 (Gold, 1919). The concept of a vector triangle was, of course, not new, but Gold may have been the first to apply trigonometry to aerial navigation. During the 1920s and '30s, the advent of more reliable oxygen supplies and increased performance allowed flying at ever-greater altitudes, often above or in cloud, thus increasing the need to apply mathematics to navigation. The major advances were made during and after the Second World War. Sutcliffe's pre-war book (Air Ministry, 1939) was updated in 1960 and 1971 by *The Handbook of Aviation Meteorology* (Meteorological Office, 1971), which explains the mathematics needed to calculate most aspects of aerial navigation – based on the days when the navigator had to work out many details of the planned flight.

WORLD WAR 2 - SERIOUSLY OPERATIONAL

Many of the developments that began in the 1930s progressed at an accelerated rate during World War 2. Observational networks grew beyond all recognition, providing surface and upper-air data on a scale not seen before or since! The understanding of atmospheric processes and weather forecasting as a four-dimensional problem created the need for routine data in three dimensions. The Central Forecasting Office, at Dunstable at that time, established an upper-air bench to enhance understanding of the atmosphere and advise the 'high fliers'. It should be remembered that some civilian flying continued during the war and, in the interests of safety, meteorological information was provided, but specific security principles were applied. For example, pilots of British and Allied civil aircraft would be briefed as fully as possible, but their standing instructions said they "should not discuss with neutral pilots the conditions encountered in flight". An 'Aircraft Landing Code (ALC Code)' was prepared to provide a secure means of passing meteorological information from the ground to aircraft about to land (Air Ministry [AHB], 1954).

In World War 2, a lot of routine data were not available and the demands for meteorological support increased greatly, so the need for observed data reached a new peak. The story of meteorological reconnaissance as an essential component in acquiring data and expanding the operational capability of aviation reveals a notable phase in the development of aerial navigation (Kington and Rackliff, 2000). Crews flew missions to gather data that ideally should have been available for their pre-flight briefing. Accordingly, by definition, their work had varying degrees of built-in danger. A not-inconsiderable number of men and machines were lost attempting to make flying safer for others.

THE CIVIL AVIATION BOOM

OPPORTUNITIES TO BE TAKEN

In December 1944, a Convention on International Civil Aviation was held in Chicago and initiated the transformation of ICAN into the International Civil Aviation Organization (ICAO). By February 1946, the Provisional ICAO published *Recommendations for Standards, Practices and Procedures – Meteorology (MET)* and set the foundation for weather services to the post-war boom in commercial aviation. At the time, they still referred to the IMO, which became in 1948 the World Meteorological Organization (WMO), an agency of the United Nations. One of the aspects introduced with the internationally agreed technical regulations was the standard phraseology to be used in international aviation – it is mostly in English.

Technical advances in aviation during the Second World War transformed long-range flying to such an extent that trans-Atlantic routes could be flown routinely. Thus, meteorological services had to develop to provide flight planning and safety information. Starting in the 1930s, there was a period of some thirty to forty years when flight planning was a real task for each navigator, who had to use observed and forecast conditions in the atmosphere to make his necessary calculations. Initially, documentation was supplied for individual flights but demand increased at such a rate that individual services became impracticable and duplicated forecasts were issued for all popular routes

PRESSURE-PATTERN FLYING

The advent of pressurised aircraft flying across the Atlantic created demands for more precise navigation to cope with the safe control of air traffic. Several methods of navigation and flight planning were developed under the general term 'pressure-pattern flying'. These took advantage of new technology, which included the radio altimeter, the greatly increased network of upper-air soundings and improved understanding of relationships between atmospheric pressure and winds. The new techniques offered various options on long flights, such as determination of drift using the altimeter, single-heading flights and economies of time and/or fuel. The optimum choice may be a combination on different legs of a flight, depending on the winds. Another technique introduced is the idea of an 'equivalent headwind', defined as that constant wind which, blowing along the track at all points, results in the same average ground speed as that produced by the actual distribution of wind at the time of the flight. This was initially a fairly complicated bit of averaging but is now a calculation that computers cope with in no time. Using climatological data, mean equivalent headwinds can be calculated as a valuable aid for airline route planning.

SERVICES AT HEATHROW

Weather forecasting services flourished at Heathrow from 1946 until 1988, when technology replaced people. From Dick Ogden (1998), we learn how a newly-constructed RAF airfield became redundant in 1945 but was soon recognized as a potential new international airport for London to replace Croydon and Northolt; and so it became in 1946, with luxurious tents and wooden huts! Facilities improved in 1947, when it was standard practice for the senior forecaster to prepare a pictorial cross section for each route, showing clouds, freezing level, icing risks, etc. The upper-air forecaster added winds and temperatures for each 5° longitude zone. The flight documentation comprised forecast charts for the surface, 700 and 500 mb, cross-sectional and zonal winds, and a selection of landing forecasts for destinations and alternates. Crews collected the flight documentation and were briefed by the forecaster an hour or so before take off. Demand for meteorological services developed to such an extent that the original nucleus of a dozen staff increased to 180 in about 20 years, gradually declining thereafter as technology took over and more of the work was centralised.

CHARTS AND FORECASTS

Until the availability of electronic communications offered almost total flexibility of delivery and customisation of forecasts, meteorological information was supplied on paper, but even then flight documentation varied. The earliest examples were rather limited, as were the raw data and the performance of the aircraft.

The earliest routine, operational forecast is in the log book from Gold's office at General Headquarters in France. It is held in the National Meteorological Archive, Bracknell (Fig.14). It includes reference to the wind at 6000 ft and was on general issue to army units. By 1919, forecasts were issued specifically for the new cross-Channel airmail services (Fig.15).

Oct 24. 1916.

Army 1 } Wind light SE increasing to 15 mph later: at 6000 ft South 20 mph increasing
2 } to 35 mph. Overcast with mist and drizzle today; probably becoming bright tonight
3 } or tomorrow forenoon. Afternoon cloud low 10, rather cool.
4 } — Same as 1 & 2.
9.35 am.

1 } Wind light SE increasing to 20 mph later: overcast with
2 } mist and drizzle at first, probably becoming bright tonight or
3 }
4 } tomorrow forenoon with fair visibility. Temperature today 50 tonight 40
tomorrow 55.
11 a.

Figure 14
One of the earliest 'operational' forecasts

SPECIMEN OF REPORT ISSUED TO AERIAL MAIL SQUADRONS.

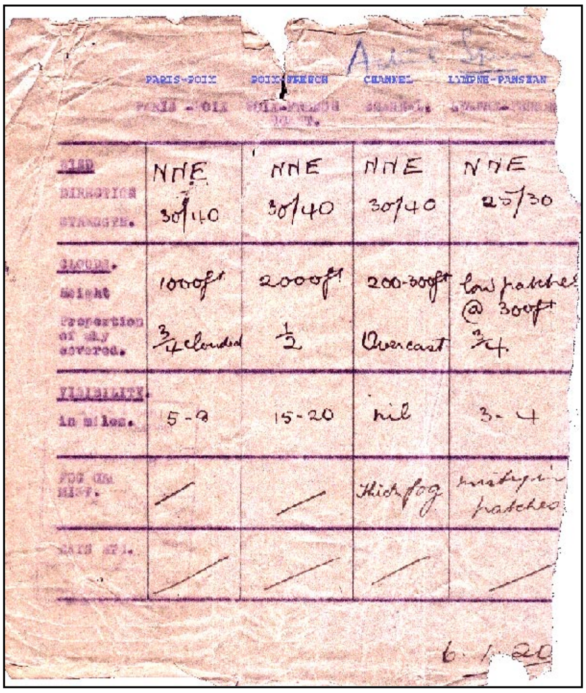
FOLKESTONE–COLOGNE AERIAL MAIL SERVICE. Weather Report at 07.00 on AUGUST 1ST. 1919.

	WEATHER				WIND.					
STATIONS	General	Cloud below 6000 ft Amount	Height	Surface Visibility	Ground (5 ft)	2000 ft	4000 ft	6000 ft	10,000 ft	Weather Prospects for next 12 hrs.
COLOGNE	Overcast with high cloud. Slight mist.	—	—	Indifferent 3 miles	SE'S 5 mph.	W'S 29 mph.	W 21 mph	W. 20 mph.	W'S 31 mph.	Mainly overcast with occasional slight drizzle at first; but fair periods probable this afternoon, with improving visibility.
ANTWERP	Overcast	10/10	6000	Indifferent 3 miles	SW'W 6 mph.	W 29 mph.	W'S 27 mph	W'S. 33 mph.		
AACHEN	Overcast with high cloud. Slight mist.	—	—	Fair 5 miles	SW'W. 10 mph.	W'S 36 mph.	W'S. 33 mph.	W. 30 mph.		
NAMUR	Overcast Slight mist.	10/10	6000	Indifferent 3 miles	SW'W 13 mph.	W 28 mph.	W'S 32 mph.	W. 36 mph.		
TOURMIGNIES	Overcast. Slight drizzle	10/10	Below 500	Very poor 1 mile	SW'W 10 mph					Continuing overcast with rain or drizzle at times. Fog likely in Channel.
WIMEREUX	Overcast Slight rain	10/10	1000	Indifferent 3 miles	SW'W 9 mph.					
MARQUIS	Overcast Slight rain	10/10	750	Indifferent 3 miles	SW 8 mph.					
CALAIS	Overcast Moderate rain	10/10	750	Fair 5 miles	SW. 10 mph.					
FOLKESTONE	Overcast. Slight mist	10/10	3500	Fair 5 miles	SW'W 10 mph					

METEOROLOGICAL SECTION, R.E. H.Q., WIMEREUX.

Figure 15
1919 forecast for the cross-Channel airmail service

It has long been recognized that it is neither useful nor practicable to archive all forecasts issued. Aviation forecasts are normally kept only when connected with an accident or incident that becomes the subject of a formal inquiry. The sample shown in Fig.16 (p.22) was found by chance in with other old papers that were unrelated.



	PARIS-POIX	POIX-FRENCH [illegible]	CHANNEL	LYMPNE-PENSHURST
WIND DIRECTION STRENGTH.	NNE 30/40	NNE 30/40	NNE 30/40	NNE 25/30
CLOUDS. Height	1000ft	2000ft	200-300ft	low patches @ 300ft
Proportion of sky covered.	3/4 clouded	1/2	Overcast	3/4
VISIBILITY in miles.	5-9	15-20	nil	3-4
FOG OR MIST.	—	—	Thick fog	[illegible] patches
RAIN ETC.	—	—	—	—

6.1.20

Figure 16
A surviving scrap of a forecast issued on 6 January 1920

The example at Fig.17 is a published version of the more elaborate forecasts that had been introduced by 1917. The revised system was developed to provide a more elaborate service, issued as *Meteorological Section G.H.Q. Chart of Weather in North Western Europe at* [*time and date*]. At 9.15 a.m., a forecast of weather for 'noon today to noon tomorrow' was issued, including a 6000 ft wind. Also included was a chart with a summary of weather for the past 24 hours, a general outlook, details of the past 24 hours' rainfall, weather and cloud, and diagrams of 'wind, temperature and visibility on the British front' for yesterday afternoon and this morning. All this provided a service thought to be suitable for most military activities, except, perhaps, the ballistic winds needed by the artillery.

In the late 1920s, the dream of routine intercontinental airship services encouraged the idea of radio-facsimile communications as previously described.

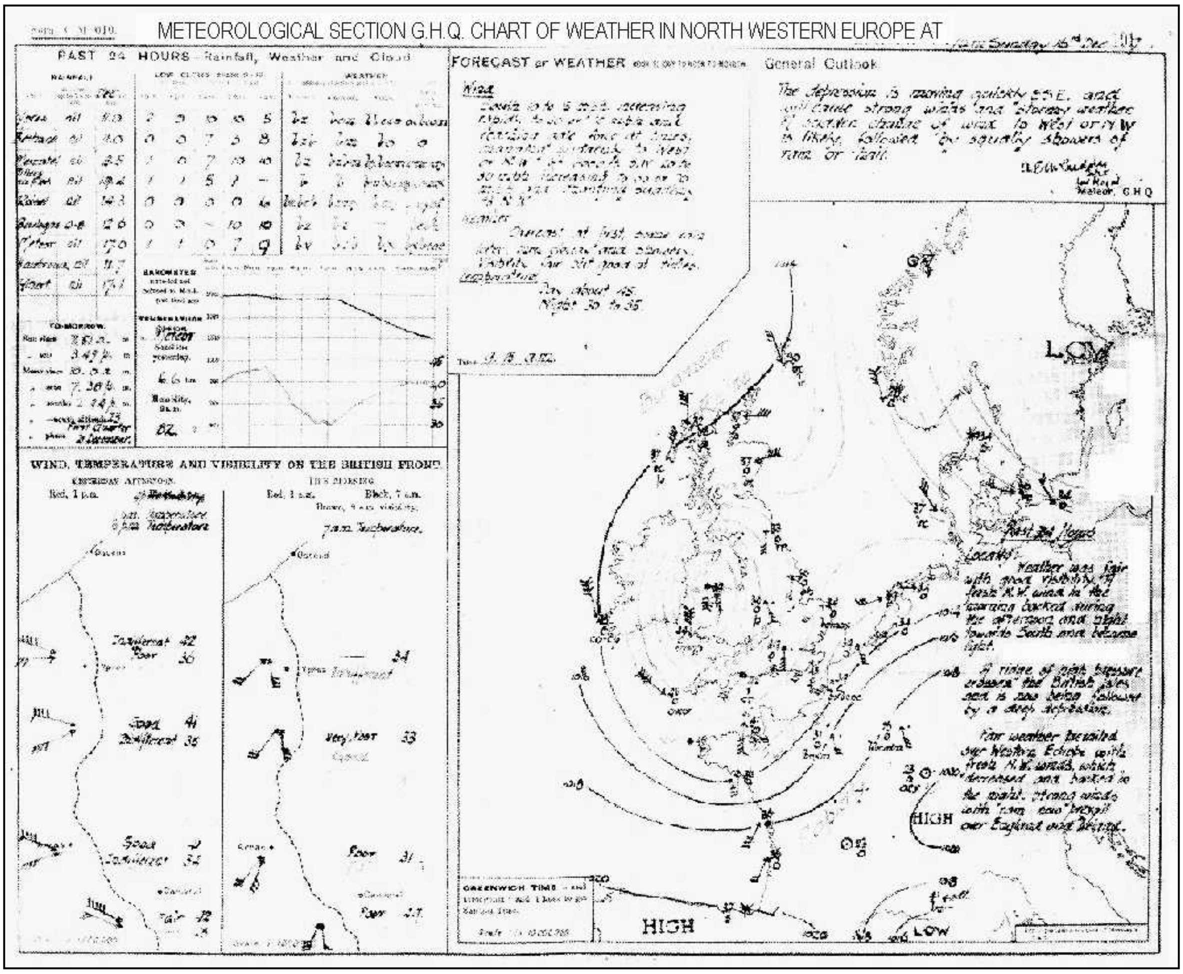


Figure 17
1917 report and forecast for the Military

Trans-Atlantic passenger flights were mainly experimental in the late 1930s, when the new breed of flying boats came on the scene. Research into services and long-range forecasting was overseen by S P Peters, an experienced ex-Airship Division forecaster, with the aid of new graduate recruits like P J Meade, who was one of the first to provide forecasts for flying boats (Meade, 1993). The majestic Short 'C' class flying boats of Imperial Airways did not have the range to fly non-stop from their base in Southampton Water to Newfoundland; instead, they flew from Foynes in Eire. The Boeing Clippers of Pan American had similar limitations. Although the Government of Eire were responsible for meteorological services in their country, they accepted Meteorological Office staff at Shannon for investigative and forecasting work.

By the 1930s, commercial flights were supplied with individually prepared documentation which by the 1940s began to include trans-Atlantic charts marked with a great circle and a rhumb line between Shannon and Newfoundland.

After the upheaval of the War, the provision of meteorological information for aviation became more ordered. By the mid 1950s, there were definitions:

- Flight forecasts - usually issued to aircrew for specific flights and times.
- Route forecasts - usually issued for specific routes but covering a range of times (ETAs and ETDs). Often supplied by main offices to form the basis of flight forecasts prepared elsewhere.
- Local forecasts - for flying during the specified period around a particular airfield.
- Area forecasts - similar to local but covering a wider area.
- [Terminal] aerodrome forecasts – specifically covering landing conditions at one location during a particular period. Became known as TAFs.

Early advice to aircrew was that they should interpolate between the actual chart and the forecast chart to assess the situation at the time they expected to fly a particular leg. With increasing range and duration, this became more difficult and the concept of a 'variable' time forecast was developed (see Figs. 18 and 19). This was approved by J S Sawyer, another major figure in the development of aviation meteorology in the third quarter of the 20th century.

FORECAST ON FORM 2330A

FORM 2330A **FLIGHT AND AERODROME FORECAST** DATE .... 195..

FROM OAKINGTON TO MIDDLETON ST. GEORGE VIA DIRECT ROUTE

General Features of the Meteorological Situation

An unstable northwesterly airstream covers the British Isles

Flight Forecast Valid for Period 0900 G.M.T. to 1100 G.M.T.

STAGE	From / To	OAKINGTON / MIDDLETON ST. GEORGE
WINDS (deg. true and knots) AND TEMPS (deg. C.)	2,000 ft.	300 deg. 25 kt. slowly veering to 320 deg. 35 kt. (+8)
	5,000 ft.	310 deg. 27 kt. slowly veering to 320 deg. 40 kt. (-0)
	10,000 ft.	300 deg. 35 kt. (-09)
	15,000 ft.	300 deg. 45 kt. (-17)
	20,000 ft.	290 deg. 55 kt. (-25)
	30,000 ft.	290 deg. 70 kt. (-43)
		Tropopause 33,000 ft. falling to 32,000 ft. (-54)
WEATHER		Partly cloudy in south, becoming locally cloudy in north with occasional showers, perhaps with hail and thunder by end of period. Local hill fog in showers.
SURFACE VISIBILITY		20 nm., falling to 5 nm. in most showers, but locally 2,000 yd. in occasional heavier precipitation.
CLOUD (All heights are above Mean Sea Level)		2/8 to 4/8 Cu at first, base 3,000 ft., tops 6,000 ft., increasing northwards to 5/8 to 7/8 Cu, base mainly 2,500 ft. and tops 8,000 ft. to 12,000 ft., but base falling locally to 1,500 ft. in scattered Cu. Nim. Occasional tops to 20,000 ft. in north of route.
Height of 0 deg. C. Isotherm		5,500 ft. falling to 4,500 ft. in north.
Airframe Icing		Nil or light, becoming mod., locally severe in north
Contrail Levels Between		25,000 ft. and 33,000 ft.

AERODROME FORECAST for Middleton S.G. Valid for Period 1000 G.M.T. to 1100 G.M.T.

SURFACE WIND 270 deg. (true) 15 kt. gusting to 20 kt.

WEATHER
Partly cloudy.
Occasional showers.
Local hail and thunder.

SURFACE VISIBILITY
20 nm. falling to 5 nm. in some showers but occ. 2,000 yd.

CLOUD
5/8 Cu, base 2,500 ft.
In most showers 7/8 Cu or Cu. Nim, base generally 2,000 ft. but 1,500 ft. in heavier showers.
(Heights are above ground level)

REMARKS
Nil.

Issued by W. E. A[illegible] at OAKINGTON Meteorological Office at 0830 G.M.T.

Figure 18
An example of the form used for forecasts for shorter flights

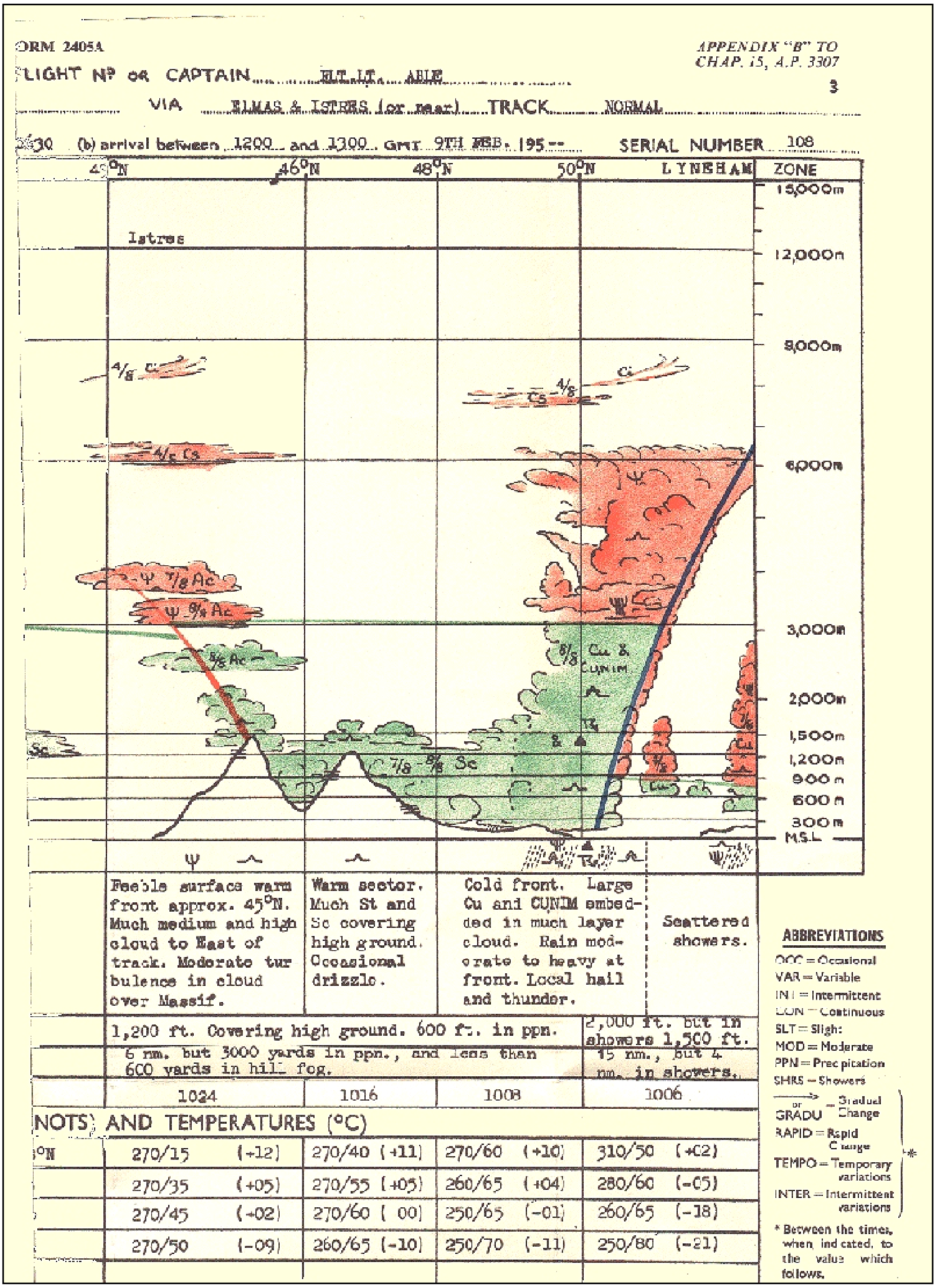


Figure 19

Part of a cross-section forecast used for longer flights

By the 1960s, the growth in aviation activity had outstripped the ability of the meteorological services to tailor forecasts for all individual flights. To cope with this, self-explanatory charts had increasingly been introduced. Examples of the styles used in the 1960s and '70s are shown in Figs.20 and 21. Use was made of the numerical forecast products from the growing main frame computers, but human interpretation, and writing, was still standard operational practice. Other new tools were becoming more widely available to the forecasters, such as weather radar and satellite pictures.

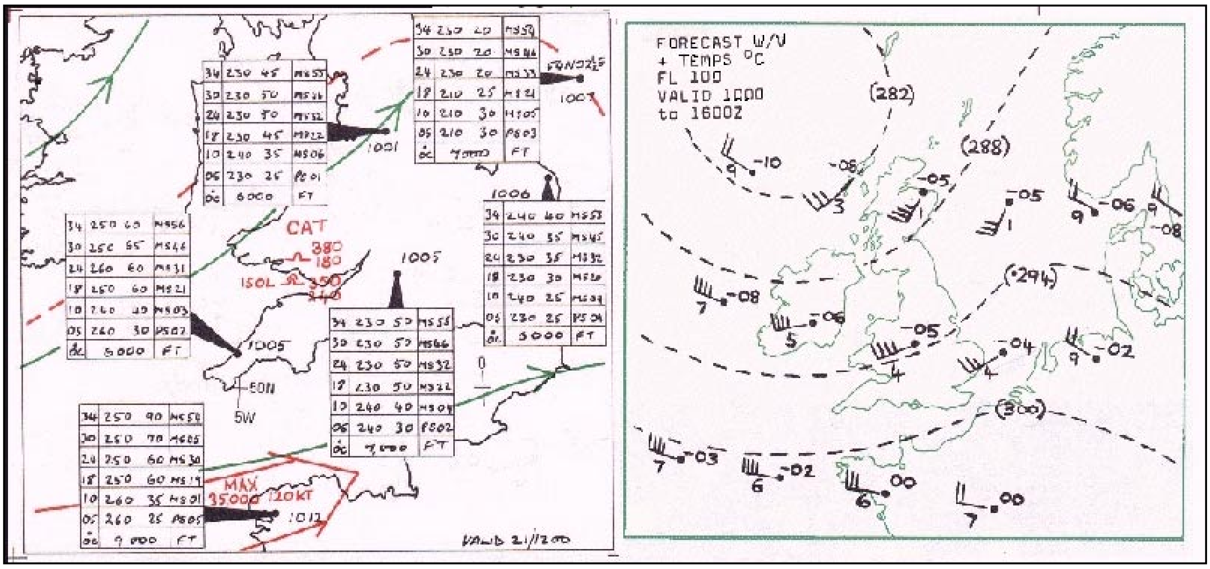


Figure 20
Two styles of presenting forecast upper winds

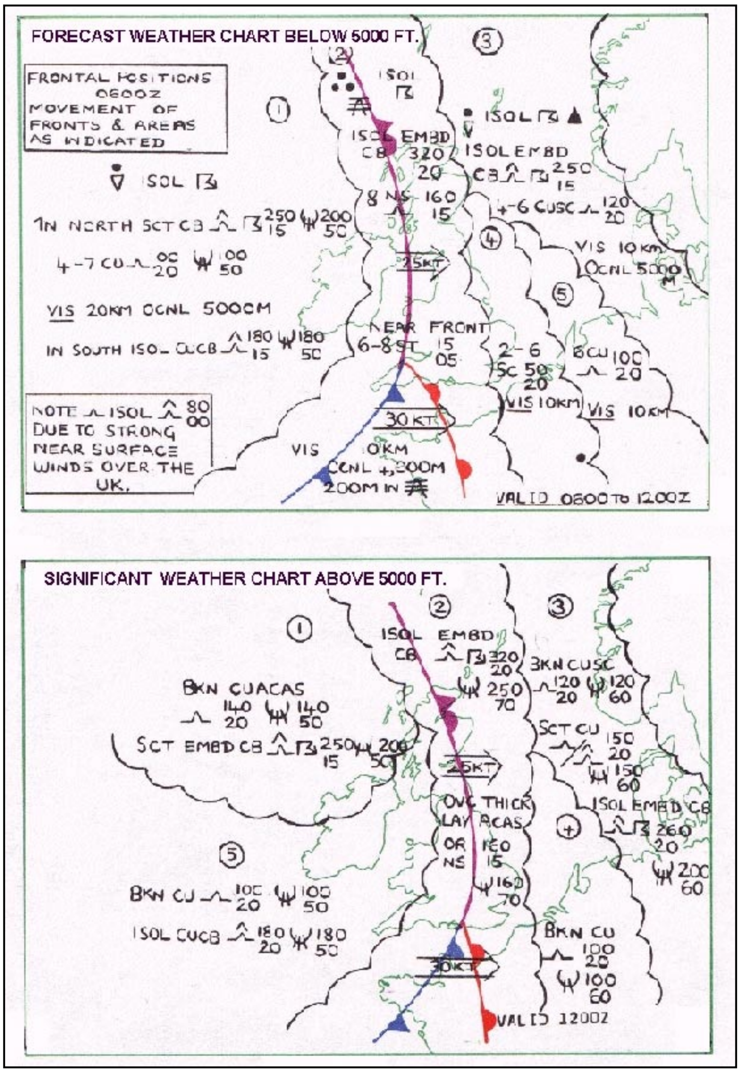


Figure 21
Forecast weather in chart form

21st CENTURY

Increasingly by the late 20th century, both automatic data-gathering and analysis and numerical weather forecasting had become linked directly with flight-planning computers for most of the major airlines. By the start of the 21st century, there were still some differences in detail between meteorological services for military and civil aviation, although moves were afoot to merge some procedures. Clearly there will always be some military flying that cannot use routine output from a major weather forecasting centre.

The increased sophistication of computerised data gathering, exchange and analysis and modern numerical forecasting have reduced the need for many national meteorological services to duplicate the work of others to produce forecasts for international flying. Services for international airlines are provided by the main World Area Forecast Centres. In 2001, these were Bracknell in the UK and Washington in the USA, with some regional products from Tokyo and Melbourne. The major airlines receive the required information via computer links with updates and additional notices and warnings available on the flight deck via satellite communication links. For examples of meteorological forecast products available to aviators today, see Figs. 22-26.

While the airline industry and communications become more international and the need for forecast service locations decreases, commercial competition has encouraged a proliferation of private service providers. Almost anyone with a telephone and an on-line computer can offer a weather forecast service without necessarily having the scientific backup available to members of the World Meteorological Organization. Many dozens are available on the Internet alone. *Ad hoc* arrangements are obviously necessary for unscheduled flights and for general and private aviation. Modern communications offer a flexibility of information exchange that was undreamed of only 30 years ago.

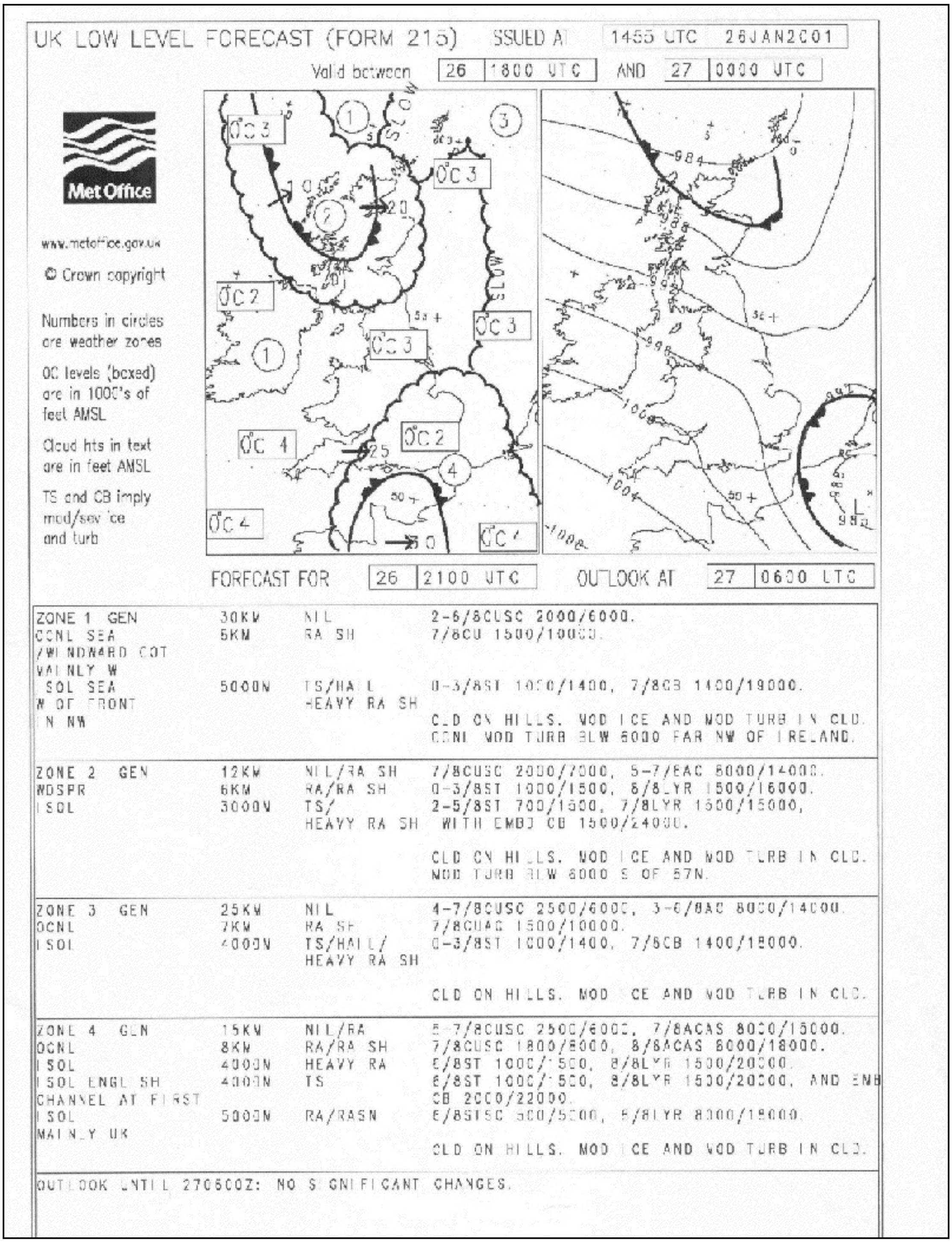
Aviation services for such flying are summarised in a small booklet issued by the Civil Aviation Authority and the Met Office (Met Office and Civil Aviation Authority; 2001). The contents of this publication include a pilot's pre-flight check list about flight planning and sections in respect of the following:

- Services via the Internet
- Dial-up fax forecasts and bulletins for pilots.
- Services via the telephone
- AIRMET areas and boundaries
- Automated METAR and TAF service (with sections outlining how to decode the airfield actual reports and landing forecasts)
- VHF Volmet
- Various contact points (e.g. where to send a flight plan) and a summary of services from some other European countries.

Taking advantage of modern technology, pilots can buy any information they need to help them fly more safely. The trend continues towards a system with decreasing human contribution, although it would seem certain that 'old fashioned' flying will always remain popular as a leisure activity.

FULLY COMPUTERIZED – who needs a navigator anyway?

Global communications via satellites have virtually removed the need for information to be supplied on paper; many airlines are able to call up, in flight, for landing forecasts, actual weather reports and almost any other additional information required by the aircrew. Satellite position fixing (GPS) has become so commonplace on land and in the air that track corrections depending on forecast winds and weather have almost become a thing of the past. In little more than two hundred years, the wheel has turned full circle from 'navigation' skills being barely possible to them becoming barely necessary for many aviators; except perhaps the real enthusiast for 'seat of the pants' flying. Perhaps one day all of the process may become computer controlled, but it is a brave 'forecaster' who thinks mother nature can be ignored. Even in the late 20th century, the weather is a factor in over a fifth of aviation accidents. So while finding the way from one point on earth to another is now fairly straightforward, there remains the problem of navigating around shorter term problems like thunderstorms, microbursts, clear air turbulence, icing, etc. A lot of resources and scientific effort are still being invested in research to avoid or counteract these potential hazards. But accidents will still happen when aviators take the weather for granted and ignore the warnings from meteorological advisors, or the signs visible to that most valuable, fundamental tool of all aviators - *the eyeball Mark I, pilots, for the use of*!!!!



UK LOW LEVEL FORECAST (FORM 215) ISSUED AT 1455 UTC 26JAN2001

Valid between 26 1800 UTC AND 27 0000 UTC

Met Office

www.metoffice.gov.uk

© Crown copyright

Numbers in circles are weather zones

0C levels (boxed) are in 1000's of feet AMSL

Cloud hts in text are in feet AMSL

TS and CB imply mod/sev ice and turb

FORECAST FOR 26 2100 UTC

OUTLOOK AT 27 0600 UTC

ZONE 1 GEN	30KM	NIL	2-6/8CUSC 2000/6000.
OCNL SEA /WINDWARD COT MAINLY W	5KM	RA SH	7/8CU 1500/10000.
ISOL SEA W OF FRONT IN NW	5000M	TS/HAIL HEAVY RA SH	0-3/8ST 1000/1400, 7/8CB 1400/19000.
			CLD ON HILLS. MOD ICE AND MOD TURB IN CLD. OCNL MOD TURB BLW 5000 FAR NW OF IRELAND.
ZONE 2 GEN	12KM	NIL/RA SH	7/8CUSC 2000/7000, 5-7/8AC 8000/14000.
WDSPR	6KM	RA/RA SH	0-3/8ST 1000/1500, 8/8LYR 1500/16000.
ISOL	3000M	TS/ HEAVY RA SH	2-5/8ST 700/1500, 7/8LYR 1500/15000, WITH EMBD CB 1500/24000.
			CLD ON HILLS. MOD ICE AND MOD TURB IN CLD. MOD TURB BLW 6000 S OF 57N.
ZONE 3 GEN	25KM	NIL	4-7/8CUSC 2500/6000, 3-6/8AC 8000/14000.
OCNL	7KM	RA SH	7/8CUAC 1500/10000.
ISOL	4000M	TS/HAIL/ HEAVY RA SH	0-3/8ST 1000/1400, 7/8CB 1400/18000.
			CLD ON HILLS. MOD ICE AND MOD TURB IN CLD.
ZONE 4 GEN	15KM	NIL/RA	5-7/8CUSC 2500/6000, 7/8ACAS 8000/15000.
OCNL	8KM	RA/RA SH	7/8CUSC 1800/8000, 8/8ACAS 8000/18000.
ISOL	4000M	HEAVY RA	6/8ST 1000/1500, 8/8LYR 1500/20000.
ISOL ENGLISH CHANNEL AT FIRST	4000M	TS	6/8ST 1000/1500, 8/8LYR 1500/20000, AND EMB CB 2000/22000.
ISOL MAINLY UK	5000M	RA/RASN	6/8STSC 500/5000, 8/8LYR 8000/18000.
			CLD ON HILLS. MOD ICE AND MOD TURB IN CLD.

OUTLOOK UNTIL 270600Z: NO SIGNIFICANT CHANGES.

Figure 22

Civil low-level UK forecast aimed at general aviation

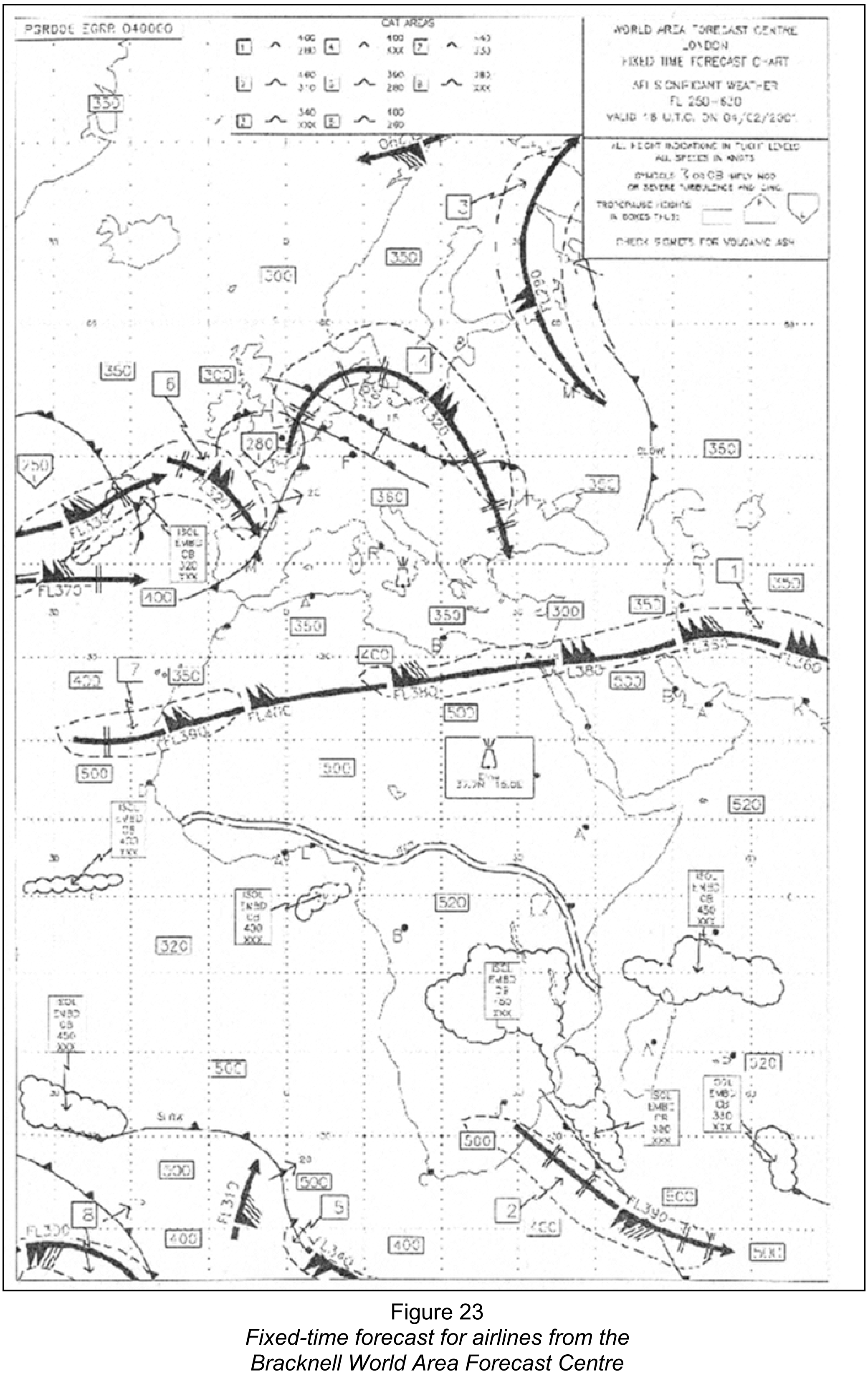


Figure 23
Fixed-time forecast for airlines from the Bracknell World Area Forecast Centre

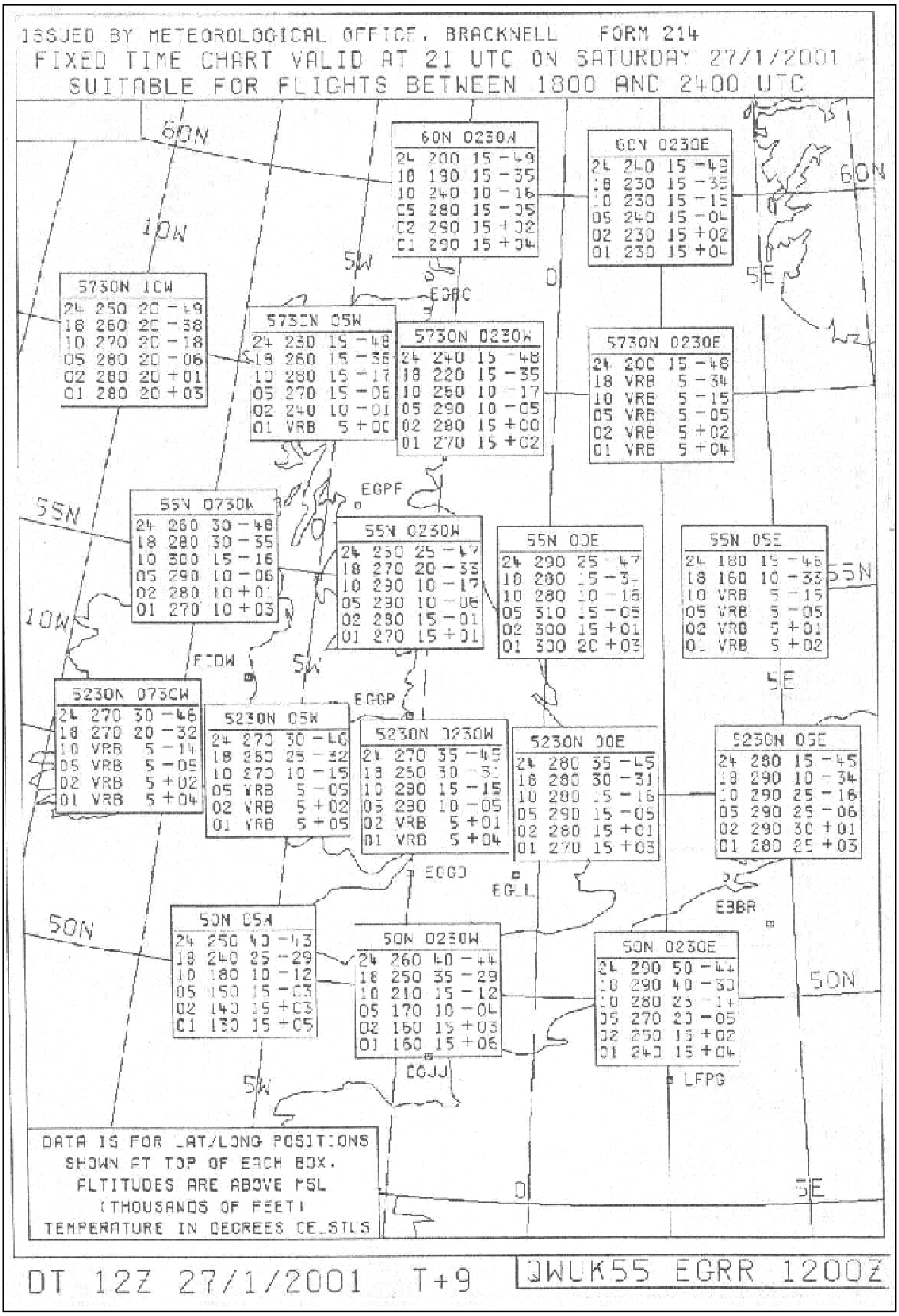


Figure 24

Tabulated spot-wind forecast – for DIY navigators

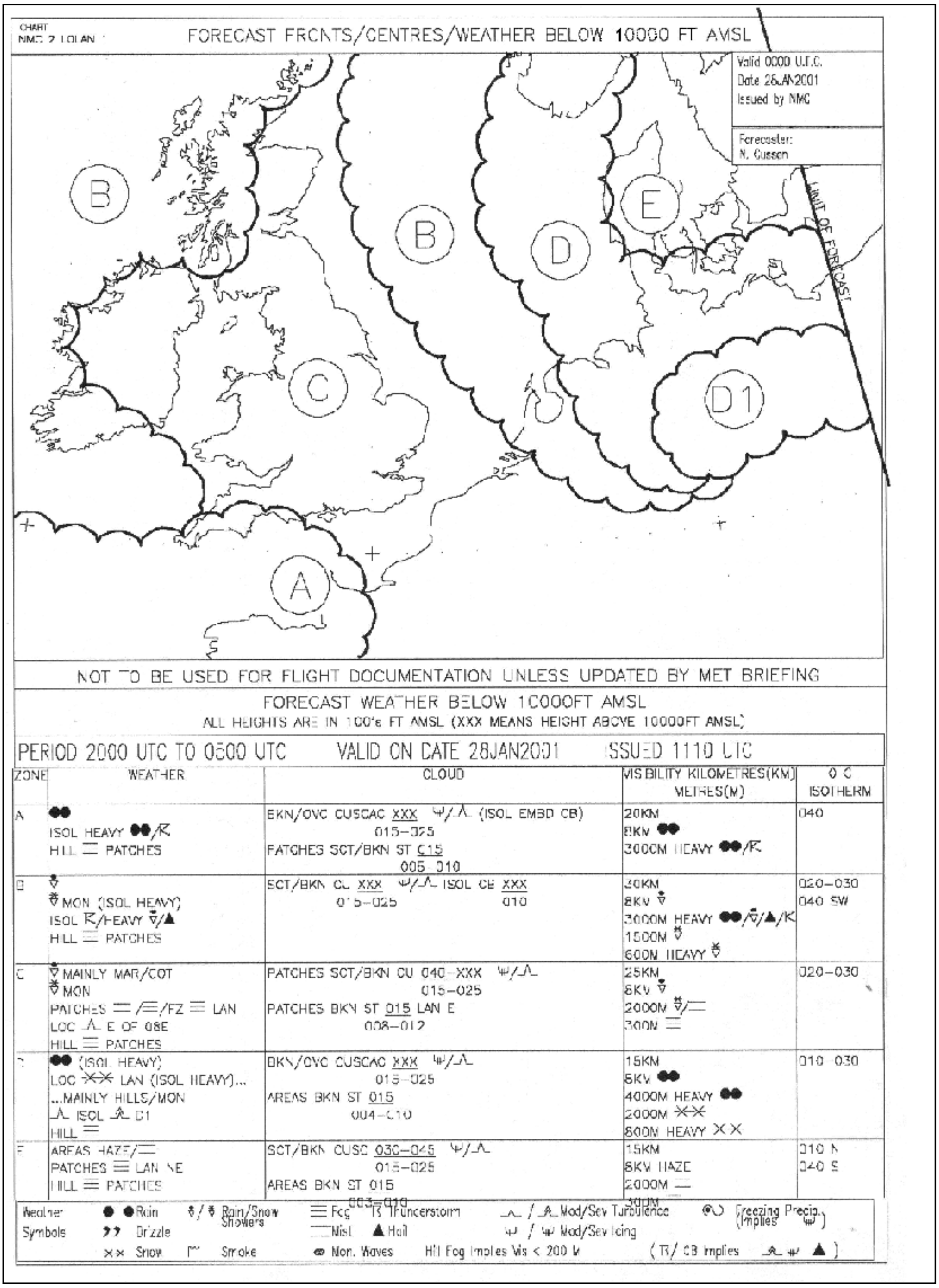


CHART NMC 2 LOLAN

FORECAST FRONTS/CENTRES/WEATHER BELOW 10000 FT AMSL

Valid 0000 U.T.C.
Date 28JAN2001
Issued by NMC

Forecaster:
N. Gusson

NOT TO BE USED FOR FLIGHT DOCUMENTATION UNLESS UPDATED BY MET BRIEFING

FORECAST WEATHER BELOW 10000FT AMSL

ALL HEIGHTS ARE IN 100's FT AMSL (XXX MEANS HEIGHT ABOVE 10000FT AMSL)

PERIOD 2000 UTC TO 0600 UTC VALID ON DATE 28JAN2001 ISSUED 1110 UTC

ZONE	WEATHER	CLOUD	VISIBILITY KILOMETRES(KM) METRES(M)	0 C ISOTHERM
A	ISOL HEAVY HILL PATCHES	BKN/OVC CUSCAC XXX (ISOL EMBD CB) 015–025 PATCHES SCT/BKN ST 015 005–010	20KM 8KM 3000M HEAVY	040
B	MON (ISOL HEAVY) ISOL /HEAVY HILL PATCHES	SCT/BKN CU XXX ISOL CB XXX 015–025 010	30KM 8KM 3000M HEAVY 1500M 600M HEAVY	020–030 040 SW
C	MAINLY MAR/COT MON PATCHES //FZ LAN LOC E OF 08E HILL PATCHES	PATCHES SCT/BKN CU 040–XXX 015–025 PATCHES BKN ST 015 LAN E 008–012	25KM 8KM 2000M 300M	020–030
D	(ISOL HEAVY) LOC LAN (ISOL HEAVY)... ...MAINLY HILLS/MON ISOL D1 HILL	BKN/OVC CUSCAC XXX 015–025 AREAS BKN ST 015 004–010	15KM 8KM 4000M HEAVY 2000M 800M HEAVY	010–030
E	AREAS HAZE/ PATCHES LAN NE HILL PATCHES	SCT/BKN CUSC 030–045 015–025 AREAS BKN ST 015 003–010	15KM 8KM HAZE 2000M 300M	010 N 040 S

Weather Symbols: Rain; Rain/Snow Showers; Fog; TS Thunderstorm; Mod/Sev Turbulence; Freezing Precip. (Implies); Drizzle; Mist; Hail; Mod/Sev Icing; Snow; Smoke; Mon. Waves; Hill Fog Implies Vis < 200 M; (TS/ CB Implies)

Figure 25
Forecast issued for the RAF

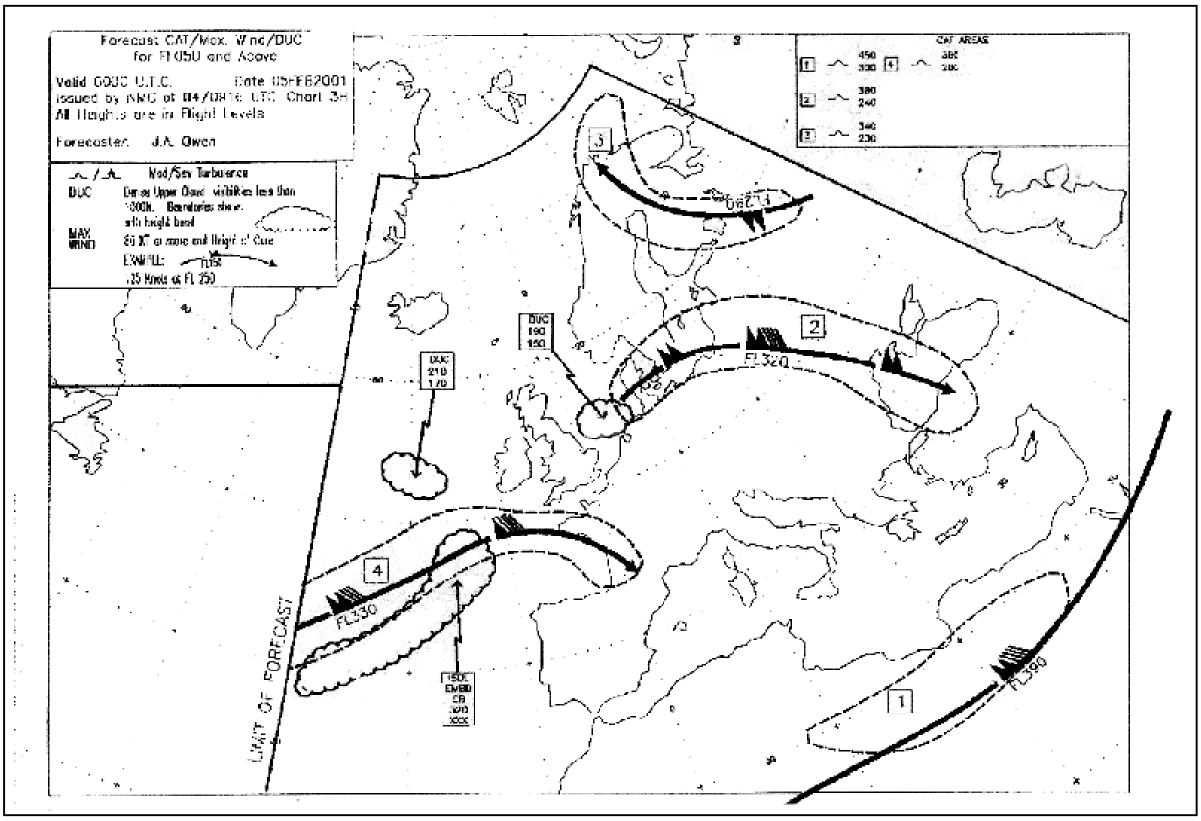


Figure 26
Maximum wind and clear-air turbulence forecast for the RAF

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