The background of the cover is a high-resolution aerial remote sensing image. It shows a complex landscape with various colors: green for vegetation, blue for water bodies, and a mix of red, orange, and white for urban or developed areas. A grid of semi-transparent grey squares is overlaid on the entire image. A dark horizontal band is positioned across the upper middle section, containing the title. Below it, a lighter grey band contains the author's name. In the bottom left corner, there is a small blue and white logo.

# The Remote Sensing Data Book

Gareth Rees



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GARETH REES



**CAMBRIDGE**  
UNIVERSITY PRESS

PUBLISHED BY THE PRESS SYNDICATE OF THE UNIVERSITY OF CAMBRIDGE  
The Pitt Building, Trumpington Street, Cambridge, United Kingdom

CAMBRIDGE UNIVERSITY PRESS

The Edinburgh Building, Cambridge CB2 2RU, UK <http://www.cup.cam.ac.uk>  
40 West 20th Street, New York, NY 10011-4211, USA <http://www.cup.org>  
10 Stamford Road, Oakleigh, Melbourne 3166, Australia

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First published 1999

Printed in the United Kingdom at the University Press, Cambridge

Typeset in 9/12pt Times [wv]

*A catalogue record for this book is available from the British Library*

*Library of Congress Cataloguing in Publication data*

Rees, Gareth (William Gareth), 1959–

The remote sensing data book / Gareth Rees.

p. cm.

ISBN 0 521 48040 X

1. Remote sensing -- Handbooks, manuals, etc. 2. Remote sensing --  
Dictionaries. I. Title.

G70.4.R435 1999

621.36'78--dc21 98-30283 CIP

ISBN 0 521 48040 X hardback

*For Christine*

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# Preface

## What is remote sensing?

Remote sensing is, rather broadly speaking, the obtaining of information about an object without actually coming into contact with it. A more restricted definition includes the stipulations that the object is located on or near the Earth's surface, that the observations are made from above the object, and that the information is carried by electromagnetic radiation, some measurable property of which is affected by the object being sensed. This narrower definition excludes such techniques as sonar, geomagnetic and seismic sounding, as well as medical imaging, but includes a wide and fairly coherent set of techniques, often known by the alternative name of *Earth Observation*, that form the subject of this book.

Remote sensing can be viewed as an extension of aerial photography, and thus dated to (probably) 1858, when Tournachon made the first aerial photograph from a balloon at a height of about 80 metres. In the century and a half since then, three principal developments can be identified: the possibility of using aircraft (from the early years of the twentieth century) and spacecraft (from the 1960s) as platforms to carry sensors; the development of sensors exploiting a much wider range of the electromagnetic spectrum than is responded to by photographic film; and the computer revolution, which can again probably be dated to the 1960s and which still appears to be in full swing.

Remote sensing has seen dramatic growth over the last few decades. In part, this can be attributed to the technical developments just outlined, but it is clear that remotely sensed data (in the sense in which I have defined them) must also have some tangible advantages to justify the expense of acquiring and analysing them. These advantages derive from a number of characteristics of remote sensing. Probably the most important of these is the fact that data can be gathered from a large area of the Earth's surface (or a large volume of the atmosphere) in a short space of time, allowing a virtually instantaneous 'snapshot' to be obtained. For example, the Landsat Thematic Mapper, a spaceborne instrument, can acquire data from an area 185 km square in about half a minute. When this aspect is combined with the fact that airborne and spaceborne systems can obtain information from locations that would be difficult (slow, expensive, dangerous, politically awkward) to measure *in situ*, the potential power of remote sensing becomes

apparent. Further advantages derive from the fact that most remote sensing systems now generate calibrated digital data which can be manipulated in a computer.

Remote sensing finds a very wide range of applications including, famously, military reconnaissance. The great majority of the non-military applications, with which this book deals, can be loosely categorised as 'environmental', and we can distinguish a range of environmental properties that can be sensed. In the atmosphere, these include temperature, humidity, precipitation, and the spatial distribution of clouds, winds, aerosols and minor constituents, especially ozone. The Earth's radiation budget can also be measured. Over land surfaces, topography, temperature, albedo, vegetation type and distribution, rock type, soil moisture and land use can all be measured. Over ocean surfaces, colour (which is often related to biological productivity), temperature, topography (from which surface currents can be inferred), wind velocity and wave spectra can be measured. Finally one should mention the cryosphere, where the distribution and condition of snow, sea ice, icebergs and glaciers and ice sheets can be monitored.

This wide range of measurable physical properties generates a correspondingly wide range of applications. Again it is not practicable to present an exhaustive list, but the major non-military applications can perhaps be categorised as follows:

#### Atmosphere

- weather forecasting
- stratospheric chemistry
- global climate research

#### Land surface

- cartography
- land-use surveying
- agriculture and forestry mapping and monitoring
- geological and geomorphological mapping
- geodetic mapping and observation of tectonic motion
- hydrological assessment and forecasting
- resource mapping
- hazard and disaster assessment

#### Oceans

- coastal zone management
- wave forecasting
- measurement of sea-floor topography and determination of the oceanic geoid
- location of fishing areas
- monitoring surface pollution

#### Cryosphere

- snow monitoring and runoff prediction
- sea ice and icebergs
- glaciers and ice sheets

## Aim and scope of this book

This book was conceived with several aims in mind. For the comparative newcomer, it attempts to provide brief definitions of terms and concepts commonly encountered in remote sensing. For the more experienced practitioner, the book collects reference data that are often scattered rather widely throughout the existing literature, and it also aims to provide an insight into the wide range of applications of remote sensing so that specialists in one area can obtain helpful insights from others.

The book is organised alphabetically, as a dictionary, in order to facilitate the location of information from unfamiliar areas. Extensive cross-referencing should ensure that the required entry can be found even if the user is unsure of the best starting point. The entries cover the following main areas: definitions and surveys of the principal types of remote sensing system; definitions of the concepts defining the operation and performance of remote sensing systems; propagation and scattering of electromagnetic radiation; characterisation of the Earth's atmosphere; the orbital dynamics of satellites; brief notes on the principal space agencies; remote-sensing satellites; spaceborne remote sensing instruments; concepts and techniques of image processing of remotely sensed data. Brief notes on a number of important applications of remote sensing are also included.

The book addresses itself to remote sensing of the Earth's surface and atmosphere from space. Airborne systems are excluded, although reference is made to them where appropriate. Similarly, the majority of short-duration Space Shuttle missions are not described. Observation programmes directed primarily towards astronomy or the exploration of the solar-terrestrial environment are also excluded, as are specifically military applications.

A comment is appropriate with regard to the information provided on space agencies. The last few years have seen an increasing trend towards spaceborne missions operated jointly by national (or international) space agencies and by commercial companies, and it seems likely that this trend will continue. The book therefore includes some information on relevant commercial operators; naturally, such inclusion constitutes neither an advertisement for nor an endorsement of the company in question.

While the editor and contributors have made every effort to ensure that the book is as up-to-date as it can be, consistent with publishing timetables, some 'dating' of the material is inevitable as a result of the rapid evolution of national and international Remote Sensing programmes. The book attempts to address this fact by including information on the major satellite programmes and missions planned for the next ten years or so. Some of this information is necessarily provisional, and in order to help the user of this book to keep track of changes in mission profiles, relevant World Wide Web (Internet) addresses (URLs, or uniform resource locators) have been included wherever they have been thought helpful. There are also a number of useful WWW pages providing general information on remote sensing, particularly NASA's 'Space Hotlist', CEOS's 'Yellow Pages' and the Centre for Earth Observation's pages. At the



time of writing, the URLs of these sites are

<http://www.hq.nasa.gov/osf/hotlist/>

<http://www.smithsys.co.uk/yp/intro.htm>

<http://ewse.ceo.org/>

These and other URLs listed in the book may change over time, as may their content and relevance. The wide range of WWW search engines should enable the user to locate relevant sites in future.

This book necessarily represents a synthesis of data and information from many sources. As such, it does not readily lend itself to the provision of specific references to books and to articles published in scientific journals. A short bibliography has been provided to enable the interested reader to pursue any of the topics discussed in the book in greater depth.

## **A note about abbreviations and acronyms**

Remote sensing is a discipline that tends to generate large numbers of abbreviations and acronyms, especially in the naming of the various instruments carried by remote-sensing satellites. In general, definitions will be found under the appropriate abbreviation (for example, *ATSR*), although the definition will also be cross-referenced from the full name (*along-track scanning radiometer*). The editor believes that this policy places the definition under the more commonly used term; it also avoids the difficulty caused by the fact that, while the abbreviated name of an instrument is generally fixed, the 'expansion' of the abbreviation is not unknown to vary.

## **Errors, omissions and suggestions**

The editor accepts complete responsibility for the content and structure of the book. He would welcome suggestions for improvements.

Gareth Rees  
Cambridge

# Acknowledgements

The editor gratefully acknowledges the work of the contributors to this book, without which it could not have been written. He also thanks the following people who provided a critical review of the manuscript: Bernard Devereux, Department of Geography, University of Cambridge; Christopher S. M. Doake, British Antarctic Survey; David R. Wilson, University of Cambridge Committee for Aerial Photography; Robin G. Williams, Department of Atmospheric Science, University of Alabama in Huntsville. Thanks for patience and encouragement are due to Catherine Flack of Cambridge University Press and to Christine Rees.

## **The Remote Sensing Data Book**

*The Remote Sensing Data Book* provides a unique resource of all aspects of remote sensing for the expert and non-expert alike. Organised as a dictionary, it contains over 700 alphabetically-arranged and cross-referenced entries on how remote sensing works, what kinds of data are available, and the large number of satellites and instruments from which the information is obtained. As well as short technical definitions, it also includes longer essays and reviews to give an overview of the subject. Although not a textbook in itself, the data book will serve as a valuable addition to existing textbooks for undergraduates and graduate students taking geography, environmental and earth science courses that include an element of remote sensing. It will also be an essential reference for researchers and research managers at all levels who use spaceborne remote sensing methods to obtain information about the Earth's land, sea, ice and atmosphere.

GARETH REES read natural sciences at the University of Cambridge, specialising in physics and theoretical physics, and took a PhD in radio astronomy. He is a fellow of Christ's College, Cambridge, and Head of the Remote Sensing Group at the Scott Polar Research Institute. His research interests relate to the application of satellite remote sensing methods to polar environments, especially in the Arctic. Currently his main research looks at environmental damage in the north of Russia, including air pollution and oil spills. He has published several books, including *Physical Principles of Remote Sensing* (1990), *Physics by Example* (1994), and *Essential Quantum Physics* (1997), all with Cambridge University Press.



**AATSR** (Advanced Along-Track Scanning Radiometer) U.K. optical/near infrared/thermal infrared mechanically scanned imaging radiometer, planned for inclusion on *Envisat*. Wavebands: 0.65, 0.85, 1.27, 1.6, 3.7, 11.0, 12.0  $\mu\text{m}$ . Spatial resolution: 0.5 km (wavelengths up to 1.6  $\mu\text{m}$ ), 1.0 km (wavelengths 1.6  $\mu\text{m}$  and above). Swath width: 500 km.

Like the *ATSR*, the AATSR will use a conical scanning technique which provides data from both nadir and  $52^\circ$  forward of nadir. This allows correction of the thermal infrared data for atmospheric emission and absorption effects.

URL: <http://envisat.estec.esa.nl/instruments/aatsr/index.html>

**Ablation** See *glaciers*.

**Absorption coefficient** Term describing the rate at which energy is lost from electromagnetic radiation as it propagates through an absorbing medium. If the intensity (*radiance* etc.) of the radiation propagating in the  $x$ -direction is  $I$ , the absorption coefficient  $\gamma_a$  is defined by

$$\gamma_a = -\frac{dI}{I dx}$$

and has dimensions of  $(\text{length})^{-1}$ . For constant  $\gamma_a$ , the solution of this equation is

$$I = I_0 \exp(-\gamma_a x),$$

or equivalently

$$\ln(I) = \ln(I_0) - \gamma_a x,$$

where  $I_0$  is a constant. (See *Lambert–Bouguer law*.) Absorption coefficients are sometimes also expressed in *decibel* per unit length.

See also *radiative transfer equation*, *refractive index*.

**AC** Russian broad-band UV/optical/infrared radiometer for Earth radiation budget measurements, carried on *Meteor-1* satellites. Waveband: 0.3–30  $\mu\text{m}$ . Spatial resolution: 50 km. Swath width: 2500 km.

**Accumulation** See *glaciers*.

**Accuracy, classification** See *error matrix*.

**Across-track direction** See *range direction*.

**Active Microwave Instrument** See *AMI*.

**Active system** A remote sensing system that emits radiation and analyses the returned component, such as a *lidar*, an imaging *radar*, a *radar altimeter* or a *scatterometer*. Compare *passive system*.

**ADEOS** (Advanced Earth Observing Satellite) Japanese satellite, operated by *NASDA*, launched in August 1996 with a nominal lifetime of 3 years. The satellite's solar power system failed irrecoverably in June 1997. Objectives: Global land, ocean, and atmospheric observations. Orbit: Circular *Sun-synchronous LEO* at 797 km altitude. Period 101 minutes; inclination 98.6°; equator crossing time 10:30 (descending node). *Exactly-repeating orbit* (585 orbits in 41 days). Principal instruments: *AVNIR*, *ILAS*, *IMG*, *NSCAT*, *OCTS*, *POLDER*, *TOMS*. The satellite also has a laser retroreflector array (RIS) for laser ranging from ground stations and for atmospheric absorption measurements.

ADEOS was also known as Midori.

URL: <http://www.eorc.nasda.go.jp/ADEOS/>

**ADEOS II** (Advanced Earth Observing Satellite) Japanese satellite, operated by *NASDA*, scheduled for launch in February 1999 with a nominal mission of 5 years. Objectives: Part of IEOS (International Earth Observation System – see *EOS*) for global change studies through WCRP, GEWEX, CLIVER, IGBP, GCOS, and integrated into the *EOS* programme. Orbit: Circular *Sun-synchronous LEO* at 797 km altitude. Period 101 minutes; inclination 98.6°; equator crossing time 10:30 (descending node). Principal instruments: *AMSR*, *GLI*, *ILAS-II*, *POLDER-2*, *SeaWinds*. The satellite will also carry a data collection package. ADEOS-II was formerly known as **JPOP** (Japanese Polar Platform).

URL: <http://titan.eorc.nasda.go.jp/test/GLI/adeos2.html>

**Adjacency effect** Contribution to the *radiance* (optical or near infrared) of a *pixel* by atmospherically scattered radiation originating in nearby pixels. The adjacency effect is mainly due to scattering by atmospheric *haze*, and has a horizontal scale of the order of 1 km.

**Advanced Along-Track Scanning Radiometer** See *AATSR*.

**Advanced Earth Observing Satellite** See *ADEOS*, *ADEOS II*.

**Advanced Land Observing Satellite** See *ALOS*.

**Advanced Microwave Scanning Radiometer** See *AMSR*.

**Advanced Microwave Sounding Unit** See *AMSU/MHS*, *AMSU-B*.

**Advanced Millimetre-wave Atmospheric Sounder** See *AMAS*.

**Advanced optical and Near Infrared Radiometer** See *AVNIR*.

**Advanced SAR** See *ASAR*.

**Advanced Spaceborne Thermal Emission and Reflection Radiometer** See *ASTER*.

**Advanced Synthetic Aperture Radar** See *ASAR*.

**Advanced TIROS-N** See *NOAA-6* to *NOAA-8*.

**Advanced Very High Resolution Radiometer** See *AVHRR*.

**Advanced Vidicon Camera Subsystem** See *AVCS*.

**Advanced Wind Scatterometer** See *ASCAT*.

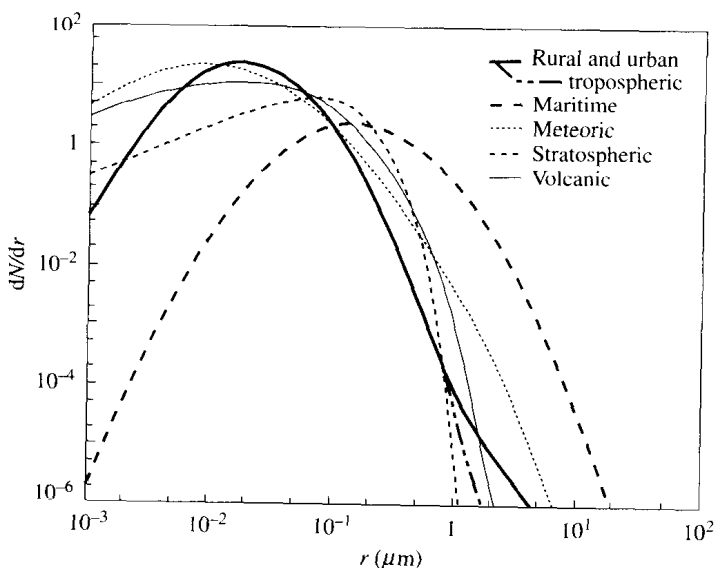
**AEM-1** See *HCMM*.

**AEM-2** (Applications Explorer Mission 2) U.S. satellite, operated by *NASA*, launched in February 1979 and terminated in November 1981. Objectives: Monitoring of stratospheric gases and aerosols. Orbit: Nominally circular *LEO* at 550 km altitude. Inclination 55°; period 97 minutes. Principal instruments: *SAGE-I*.

**Aerosol** A suspension of very small (typically 1 nm to 10  $\mu\text{m}$ ) solid particles (e.g. dust, sulphates) or liquid droplets in air, mostly found in the atmospheric *boundary layer*. Aerosols are climatically important as a result of the attenuation of solar radiation and their role in *cloud* formation. Some aerosols are also chemically active (see *chemistry, atmospheric*). Scattering and absorption of optical and near infrared radiation by aerosols is the major source of uncertainty in *atmospheric correction*. Concentrations of aerosols are difficult to measure, especially in the *troposphere* and over land, where the high surface reflectance masks the radiation scattered by the aerosol.

Aerosols of different origin have markedly different size distributions and refractive indices, and hence different absorption and scattering properties. The figure summarises the size distributions of rural, urban, tropospheric, maritime, meteoric, stratospheric and volcanic aerosols. The horizontal axis shows the particle size in  $\mu\text{m}$ ; the vertical axis the value of  $dN/dr$  where  $N$  is the concentration of particles of size  $r$ . All the graphs have been normalised to a total concentration of 1.

Over a limited range of wavelength, both the scattering and absorption coefficients of an aerosol can be described approximately by the *Ångström*



relation

$$\gamma = \gamma_0 (\lambda / \lambda_0)^{-\nu},$$

where  $\lambda$  is the wavelength and  $\gamma$  has the value  $\gamma_0$  at some reference wavelength  $\lambda_0$ .  $\nu$  is the Ångström exponent. The table below summarises the approximate values of  $\gamma_0$  (in  $\text{km}^{-1}$ ) and  $\nu$  for the optical/near infrared region, corresponding to a total attenuation coefficient of  $1 \text{ km}^{-1}$  and taking  $\lambda_0 = 0.55 \mu\text{m}$ .

Aerosol	Total		Scattering		Absorption	
	$\gamma_0$	$\nu$	$\gamma_0$	$\nu$	$\gamma_0$	$\nu$
rural	1.0	1.3	0.95	1.3	0.05	0.5
urban	1.0	1.2	0.77	1.3	0.23	0.8
tropospheric	1.0	1.8	0.97	1.8	0.03	0.8
maritime	1.0	0.2	0.99	0.2	0.01	-0.1
meteoric	1.0	0.4	0.995	0.4	0.005	-2
stratospheric	1.0	2.1	1.0	2.1	$10^{-7}$	-6
volcanic	1.0	1.2	0.94	1.2	0.06	1.2

The attenuation coefficient at sea level typically ranges between  $0.05$  and  $0.5 \text{ km}^{-1}$ ; at the tropopause it typically ranges between  $0.001$  and  $0.003 \text{ km}^{-1}$ .

Measurement of the vertical profile of aerosol scattering coefficient can be made by optical/near infrared limb sounding (e.g. *GOMOS*, *HiRDLS*, *ILAS*, *POAM-2*, *SAGE III*, *SAM-II*), backscatter lidar (e.g. *Alissa*, *GLAS*) or nadir ultraviolet/optical/infrared spectrometry (e.g. *MISR*, *MODIS-N*, *MOS*, *POLDER*).

**Agenzia Spaziale Italiana** The Italian space agency. See *CEOS*.

**AIRS** (Atmospheric Infrared Sounder) U.S. optical/infrared grating spectrometer, planned for inclusion on *EOS-PM* satellites. Wavebands: 2300 bands between 3.74 and 15.4  $\mu\text{m}$  (spectral resolution 3 nm to 13 nm), 6 bands between 0.4 and 1.7  $\mu\text{m}$ . Spatial resolution: 13.5 km horizontal (at nadir), 1 km vertical. Swath width: 1650 km (scans to  $\pm 49^\circ$  from nadir).

AIRS will provide atmospheric temperature profiles by measuring thermal emission.

URL: <http://www-airs.jpl.nasa.gov/>

**Albedo** The fraction of incident radiation that is reflected by a surface. See *bidirectional reflectance distribution function*.

**Albedo, planetary** The fraction of incident solar radiation that is reflected back into space by a planet. The Earth's planetary albedo (approximately 30%) is a fundamental factor in determining its energy budget and hence climate (see *Earth radiation budget*). It can be measured by calibrated optical/near infrared radiometry from *LEO* or from *geostationary* orbit. See *bidirectional reflectance distribution function*.

**Algorithm** A mathematical process connecting a remote sensing measurement to the surface or atmospheric property of interest.

**Aliasing** A periodic phenomenon of frequency  $f_1$ , sampled at a frequency  $f_0$ , will appear to vary with a frequency  $f_a$  given by

$$f_a = f_1 - f_0 \left[ \frac{f_1}{f_0} + \frac{1}{2} \right],$$

where  $[x]$  is the least-integer function. This phenomenon is called aliasing, and  $f_a$  is the aliased frequency. See also *Nyquist frequency*.

**Alissa** (l'Atmosphere par Lidar sur Saliout) French backscatter *lidar*, for measurement of cloud and aerosol structure, carried on *Mir-1*. Wavelength: 532 nm (Nd-YAG laser). Spatial resolution: 300 m (horizontal), 150 m (vertical). Pulse repetition frequency: 8 Hz.

**Almaz-1** Russian satellite, launched in March 1991, lifetime 1.5 years. Objectives: Global land, ocean, atmosphere observations. Orbit: Nominally circular *LEO* at 270–380 km altitude. Period 92 minutes; inclination  $73^\circ$ . Principal instruments: *SAR*, *UHF radiometer*. 'Almaz' is the Russian word for 'diamond'.

**Almaz-1B** Russian satellite, scheduled for launch in 1998 with a nominal lifetime of 3 years. Objectives: Global land, ocean, atmosphere observations. Orbit: Circular *LEO* at 400 km altitude. Period 90 minutes; inclination  $73^\circ$ . Principal instruments: *Balkan-2*, *MSU-E*, *MSU-SK*, *OEA*, *SAR-3/SLR-3*, *SAR-10*, *SAR-70*, *SROM*.



**Along-track direction** The direction on the Earth's surface parallel to the motion of a *side-looking radar* or *synthetic aperture radar*, also called the azimuth direction.

**Along-Track Scanning Radiometer** See *ATSR*.

**ALOS** (Advanced Land Observing Satellite) Japanese satellite planned for launch in 2002. Objectives: Cartography, environmental monitoring, hazard monitoring. Orbit: Circular *Sun-synchronous LEO*. Equator crossing time 10:30 descending. Principal instruments: *AVNIR-2*, *VSAR*.

The ALOS mission was formerly called HIROS.

URL: <http://www.goin.nasda.go.jp/GOIN/NASDA/act/alos.html>

**ALT** U.S. dual-frequency nadir-viewing radar altimeter, carried on *Topex-Poseidon*. Frequencies:  $K_u$  band (13.6 GHz) and C band (5.3 GHz). Pulse length (uncompressed): 102  $\mu$ s; (compressed): 3.1 ns. Range precision: 2.4 cm. Beam-limited footprint: 26 km (13.6 GHz); 65 km (5.3 GHz). Pulse-limited footprint: 2.2 km.

Dual frequency operation allows for correction of ionospheric delays.

URL: [http://www-aviso.cls.cnes.fr/English/TOPEX\\_POSEIDON/More\\_On\\_Payload.html](http://www-aviso.cls.cnes.fr/English/TOPEX_POSEIDON/More_On_Payload.html)

**Altimetry Microwave Radiometer** See *AMR*.

**Altitude, orbital** See *height, orbital*.

**AMAS** (Advanced Millimetre-wave Atmospheric Sounder) European passive microwave atmospheric limb sounder, operating in the frequency range 298–626 GHz (wavelengths 0.5–1.0 mm), planned for inclusion on *Meteor-3M* satellite. Frequencies: 298, 301, 302, 325, 346, 500, 501, 626 GHz. Spatial resolution: vertical: 1 km (troposphere); 3 km (stratosphere); 5–10 km (mesosphere). Horizontal: 300 km. Height range: 5–100 km.

AMAS is designed to measure temperature and pressure profiles, ozone, water vapour,  $N_2O$  and other chemical constituents of the middle and upper atmosphere.

**AMI** (Active Microwave Instrument) European *synthetic aperture radar*/microwave *scatterometer* carried on *ERS-1* and *-2* satellites. Frequency: C band (5.3 GHz). Polarisation: VV. Incidence angle:  $23^\circ$  at mid-swath. Spatial resolution: 30 m (wave and image modes), 50 km with data on a 25 km grid (scatterometer mode). Swath width: 5 km  $\times$  5 km (wave mode), 100 km (image mode), 500 km (scatterometer mode). Radiometric resolution: 2.5 dB in image mode, 0.3 dB in scatterometer mode.

In scatterometer mode, the AMI generates beams in directions  $45^\circ$ ,  $90^\circ$ ,  $135^\circ$  (zero is along-track,  $90^\circ$  to the right). The near edge of the swath is 150 km to the right of the sub-satellite track; the far edge is 650 km from it. Wind velocity