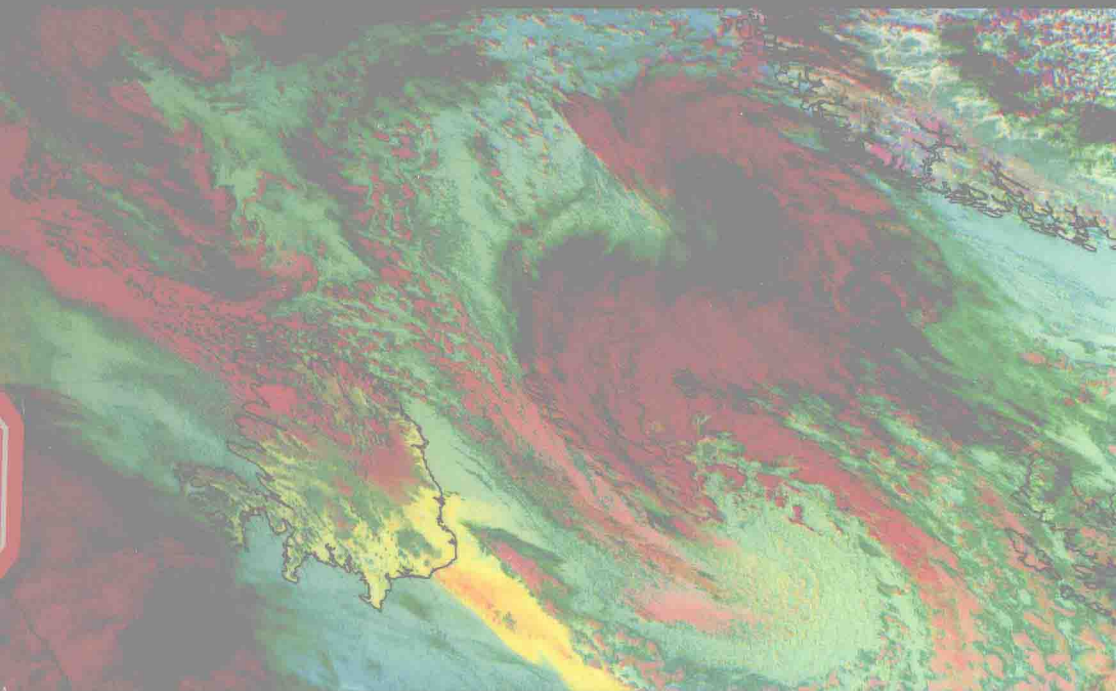


# **Infrared Observation of Earth's Atmosphere**

**Hervé Herbin  
Philippe Dubuisson**



~~Series Editor~~  
André Mariotti

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## Infrared Observation of Earth's Atmosphere

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## List of Symbols and Units of the Parameters Employed in This Book

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Airmass factor:	$m$
Albedo:	$\alpha$
Altitude:	$z$ [m]
Asymmetry factor:	$g$
Azimuth angle:	$\phi$
Bidirectional Reflectance Distribution Function (BRDF):	$\rho(s, s_i)$
Brightness temperature:	$T_B$ [K]
Complex index of refraction:	$m$
Cosine of zenith angle:	$\mu = \cos \theta$
Effective radius:	$r_e$ [m]
Emissivity:	$\varepsilon$
Exitance:	$M$ [W.m <sup>-2</sup> ]
Extinction, scattering, absorption coefficient:	$k_{ext}, k_{scat}, k_{abs}$ [m <sup>-2</sup> .kg <sup>-1</sup> ]
Extinction, scattering, absorption cross sections:	$\sigma_{ext}, \sigma_{scat}, \sigma_{abs}$ [m <sup>-2</sup> ]
Extinction scattering, absorption efficiencies:	$Q_{ext}, Q_{scat}, Q_{abs}$

Extinction, scattering, absorption	
Frequency:	$\nu$ [Hz]
Gas density:	$\rho$ [kg.m <sup>-3</sup> ]
Global Warming Potential GWP:	<i>GWP</i>
Height scale:	<i>H</i> [m]
Legendre polynomials coefficient:	$\beta_l$
Life time of a species <i>x</i> :	$\tau_x$ [s]
Liquid Water Content:	$Q_L$ [kg.m <sup>-3</sup> ]
Molar mass species <i>x</i> :	$M_x$ [kg.mole <sup>-1</sup> ]
Mueller matrix:	<b><i>S</i></b>
Net flux density:	$F^{net}$ [W.m <sup>-2</sup> ]
Optical thickness:	$\tau_{ext}, \tau_{scat}, \tau_{abs}$
Particle radius and diameter:	<i>r, D</i> [m]
Planck function:	$B_\lambda$ [W.m <sup>-2</sup> .sr <sup>-1</sup> .μm <sup>-1</sup> ]
Pressure:	<i>p</i> [Pa - hPa]
Radiative efficiency:	<i>RE</i> [W.m <sup>-2</sup> .ppb <sup>-1</sup> ]
Radiative forcing:	$\Delta F$ [W.m <sup>-2</sup> ]
Reflectance:	$\rho$
Scattering angle:	$\Theta$
Scattering phase function:	$p(\Theta)$
Single scattering albedo:	$\bar{\omega}_0$
Size distribution:	<i>n</i> [m <sup>-3</sup> ]
Size parameter:	<i>x</i>
Solar constant:	$F_\theta$ [W.m <sup>-2</sup> ]
Solid angle:	$\Omega$ [sr]
Spectral flux density (monochromatic):	$F_\lambda$ [W.m <sup>-2</sup> .μm <sup>-1</sup> ]
Spectral intensity (monochromatic):	$I_\lambda$ [W.sr <sup>-1</sup> .μm <sup>-1</sup> ]
Spectral radiance (monochromatic):	$L_\lambda$ [W.m <sup>-2</sup> .sr <sup>-1</sup> .μm <sup>-1</sup> ]
Spectral radiative flux (monochromatic):	$\Phi_\lambda$ [W.μm <sup>-1</sup> ]
Spectral source function (monochromatic):	$J_\lambda$ [W.m <sup>-2</sup> .sr <sup>-1</sup> .μm <sup>-1</sup> ]
Surface:	<i>S</i> [m <sup>2</sup> ]

Temperature:	$T$ [K]
Truncation coefficient:	$f$
Volume Mixing Ratio (VMR):	$VMR$ [ppmv]
Wave vector and number:	$k, k$ [ $\text{m}^{-1}$ ]
Wavelength:	$\lambda$ [m]
Wavenumber:	$\tilde{\nu}$ [ $\text{cm}^{-1}$ ]
Zenith angle:	$\theta$



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## List of Acronyms

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3MI:	Multi-viewing Multi-channel Multi-polarization Imaging mission
ACE-FTS:	Atmospheric chemistry experiment Fourier transform spectrometer
AFGL:	Air Force Geophysics Laboratory
AIRS:	Atmospheric infrared sounder
AU:	Astronomical unit
ATOVS:	Advanced TIROS operational vertical sounder
ATMOS:	Atmospheric trace molecules spectroscopy experiment
A-TRAIN:	Afternoon train
ATSR:	Along track scanning radiometers
AVHRR:	Advanced very high resolution radiometer
BOA:	Bottom of atmosphere
BRDF:	Bidirectional reflectance distribution function
BTD:	Brightness temperature difference
CALIOP:	Cloud-aerosol lidar with orthogonal polarization

CALIPSO:	Cloud-aerosol lidar and infrared pathfinder satellite observations
CCD:	Charge-coupled device
CERES:	Cloud and Earth radiant energy system
CkD:	Correlated k-Distribution
CLAES:	Cryogenic limb array etalon spectrometer
CPR:	Cloud profiling radar
DFG:	Deutsche ForschungsGemeinschaft
DOFS:	Degree of freedom for signal
DOM:	Discrete Ordinates Method
ECMWF:	European Centre for Medium-range Weather Forecasts
ERBE:	Earth radiation budget experiment
ESA:	European Space Agency
ESFT:	Exponential sum fitting of transmission
ETHER:	Thematic Expertise Group for Atmospheric Chemistry
FLIP:	Fictive light particle
Flx:	Flux density
GEO:	Geostationary orbit
GISS:	The NASA Goddard Institute for Space Studies
GOES:	Geostationary orbital environmental satellite
GOMOS:	Global ozone monitoring by occultation of stars
GOSAT:	Greenhouse gases observing satellite
GWP:	Global warming potential
HALOE:	Halogen occultation experiment

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HIRDLS:	High resolution dynamics limb sounder
HSR:	High spectral resolution
HWHM:	Half width at half maximum
I3RC:	Intercomparison of 3D radiation codes
IASI:	<i>Interféromètre Atmosphérique de Sondage Infrarouge</i> (infrared sensing atmospheric interferometer)
ICAO:	International Civil Aviation Organization
ICARE:	Interactions cloud aerosol radiation etc.
ICRCCM:	Intercomparison of radiation codes in climate models
IFOV:	Instantaneous field of view
IIR:	Imaging infrared radiometer
ILAS:	Improved limb atmospheric spectrometer
ILS:	Instrumental line shape
IMG:	Interferometric monitor for greenhouse gases
IPA/ICA:	Independent pixel/column approximation
IPCC:	Intergovernmental Panel on Climate Change
IR:	Infrared
IRS:	Infrared sounder
ISAMS:	Improved stratospheric and mesospheric sounder
ISCCP:	International Satellite Cloud Climatology Project
Jac:	Jacobian
JAXA:	Japan Aerospace Exploration Agency
JPL:	Jet Propulsion Laboratory
LBL:	Line-by-line algorithm

LEO:	Low Earth orbit
LLS:	Linear least square
LMD:	<i>Laboratoire de Météorologie Dynamique</i>
LMU:	Ludwig Maximilians University, Munich
LOA:	<i>Laboratoire d'Optique Atmosphérique</i>
LTE:	Local thermodynamic equilibrium
LUT:	Lookup table
MAP:	Maximum <i>a posteriori</i>
MAPS:	Measurement of air pollution from satellites
MC:	Monte Carlo
MERIS:	Medium resolution imaging spectrometer
MIPAS:	Michelson interferometer for passive atmospheric sounding
MLS:	Microwave limb sounder
MO:	Matrix operator
MODIS:	Moderate resolution imaging spectroradiometer
MOPITT:	Measurements of pollution in the troposphere
MSG:	Meteosat second generation
MTG:	Meteosat third generation
MW:	Microwaves
NASA:	National Aeronautics and Space Administration
NLLS:	Nonlinear least square
NIR:	Near-infrared
NOAA:	National Oceans and Atmosphere Administration

OCO:	Orbiting carbon observatory
OEM:	Optimal estimation method
OMI:	Ozone monitoring instrument
OSIRIS:	Optical spectrograph and infrared imager system
PARASOL:	Polarization & anisotropy of reflectances for atmospheric sciences coupled with observations from a lidar
POLDER:	Polarization and directionality of the Earth's reflectance
QDIP:	Quantum dot infrared photodetector
QWIP:	Quantum well infrared photodetector
Rad:	Radiance
RMS:	Root mean square
RTE:	Radiative transfer equation
SAGE:	Surface and atmosphere geochemical explorer
SAMS:	Surface atmospheric measurement system
ScaRaB:	Scanner for radiation budget
SCIAMACHY:	Scanning imaging absorption spectrometer for atmospheric chartography
SEVIRI:	Spinning enhanced visible and infrared Imager
SH:	Spherical harmonics
SMOW:	Standard mean ocean water
SNR:	Signal-to-noise ratio
SOS:	Successive orders of scattering
SSM/I:	Special sensor microwave imager

TANSO-FTS:	Thermal and near infrared sensor for carbon observation – Fourier transform spectrometer
TES:	Tropospheric emission spectrometer
TOA:	Top of atmosphere
TRMM:	Tropical rainfall measuring mission
Trs:	Transmission
UCSB:	University of California, Santa Barbara
UW:	University of Wyoming
UV:	Ultraviolet
VIS:	Visible
VMR:	Volume mixing ratio
VPiE:	Vapour pressure isotopologue effect
WIS:	University of Wisconsin
WMO:	World Meteorological Organization

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## Preface

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The aim of this book is not for us to rewrite a new reference book on radiative transfer or atmospheric physics and chemistry; the bibliography of this field is already very rich, such as the reference books we mention all chapters or each chapter. Here, the goal is to provide an overview of spatial infrared observations for studies on the Earth's atmosphere. The theoretical and instrumental bases and the numerical methods are summarized, as well as the main application domains, which are illustrated with the help of some concrete examples.

This book is, therefore, aimed primarily at undergraduate or Master's students in Physics and Physico-Chemistry, who will find it easy to acquire basic knowledge in this field, with the help of many illustrations, tables and summaries. However, we also think that it will be a useful resource for PhD students and researchers in related scientific fields to help better place their work in the context of current and future space missions with the help of many examples and bibliographic references contained in this book. Thus, this provides an initial theoretical overview before thorough knowledge is acquired on a specific topic associated with infrared observations of the atmosphere. For this, we selected a non-exhaustive list of key references in the field, which we present at the end of each chapter in a section called "for further information".

Before you start reading this book, we wish to draw the reader's attention to some recurring definitions throughout this book.

Much space is devoted to high spectral resolution measurements. In general, the spectral resolution of an instrument defines the capacity of its measurement to distinguish between two different wavelengths. Thus, there is no definition in the strict sense of what “high spectral resolution (HSR)” is, since it depends on the spectral variation of the object of study. However, in spectroscopy, it is common to use the term high spectral resolution for any measurement with a resolution in the order of magnitude of the Doppler width of the lines. In a broader sense, and in the case of gaseous absorption analysis by infrared remote sensing, we consider that the term HSR can be applied to all measurements, which helps solve structures of rovibrational molecules (typically  $\Delta\tilde{\nu} \leq 1 \text{ cm}^{-1}$ ).

In the field of spectroscopy, the parameter and unit which are commonly used to characterize electromagnetic waves are, respectively, the wavenumber and  $\text{cm}^{-1}$ . These can sometimes be confusing for those working in the microwave or far infrared range of the spectrum, which often use the frequency:  $\nu$  [GHz], or for those in the visible-UV domain where one is more likely to use wavelength  $\lambda$  [nm or  $\mu\text{m}$ ]. Thus, in this book, we often use the wavenumber:  $\tilde{\nu}$ , which is the number of oscillations of the electromagnetic wave per unit length. This term was introduced for the first time by Rydberg, for quantification of emissions from a hydrogen atom. Subsequently, the work on the radiation–matter interaction focused on theoretical and experimental studies of atoms. The wavenumber then became the “reference” and was often expressed in  $\text{cm}^{-1}$  to avoid having to deal with many decimal places. Since 1960, molecular spectroscopy has been booming, through the use of Fourier transform spectrometers. However, for these, the wavenumber expressed in  $\text{cm}^{-1}$  provides a direct mathematical relationship with the optical path difference [cm]. Thus, although a little “unusual”, the wavenumber in  $\text{cm}^{-1}$  is still the preferred unit for characterizing infrared measurements with high spectral resolution.

Finally, in this book, we have deliberately omitted the use of the word photon. Indeed, the term “photon” is frequently mentioned in the



field of atmospheric radiative transfer. We often find phrases such as “the direction of the photon”, “photon trajectory” and “photon mapping”. The latter term is particularly used in the case of Monte Carlo codes used for the radiative transfer in heterogeneous atmospheric environments. This misuse of the term photon has been criticized many times in atmospheric radiation literature. In modern physics, it is in fact well known that it is not possible to associate a position or a precise path to a photon and this term only should be used strictly in the context of quantum electrodynamics. Thus, based on a summary note [PUJ 15], which comments on the misuse of this term, we will use the neologism Fictive Light Particle (FLIP) as a substitute for the term photon, simple terminology but one that does not contradict the fundamental principles of modern physics.

Hervé HERBIN  
Philippe DUBUISSON  
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