Earth Explorers
The Living Planet Programme
European Space Agency

EarthCARE

The Earth Clouds, Aerosols and Radiation Explorer

Earth Explorer User Consultation Meeting 19 and 20 April 2004

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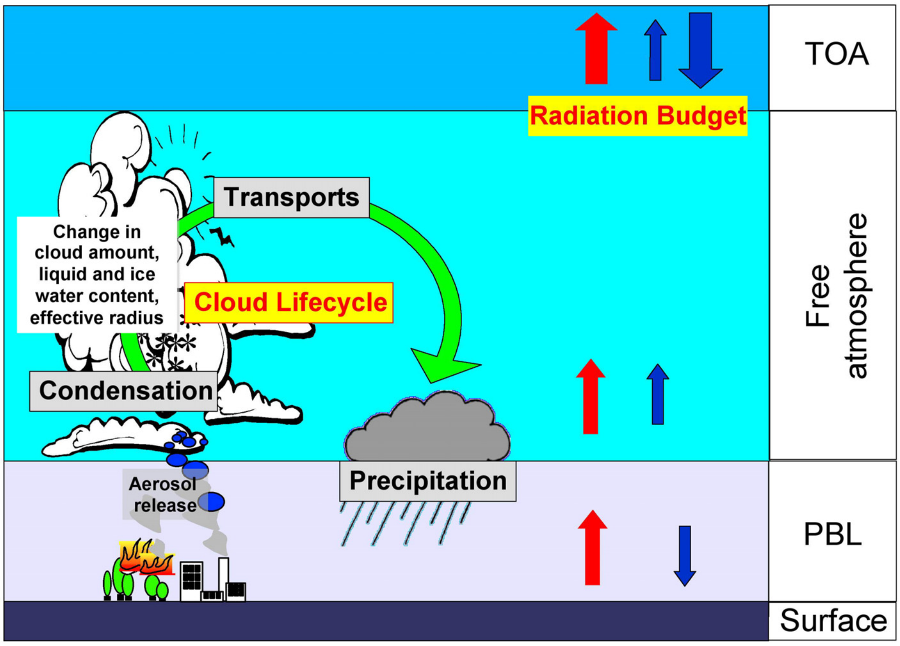
Mission Summary

EarthCARE has been defined with the specific **scientific objectives** of quantifying aerosol-cloud-radiation interactions so they may be included correctly in climate and numerical weather forecasting models to provide:

- Vertical profiles of natural and anthropogenic aerosols on a global scale, their radiative properties and interaction with clouds.
- Vertical distribution of atmospheric liquid water and ice on a global scale, their transport by clouds and radiative impact.
- Cloud overlap in the vertical, cloud-precipitation interactions and the characteristics of vertical motion within clouds.
- The profiles of atmospheric radiative heating and cooling through a combination of retrieved aerosol and cloud properties.

Scope of the Mission



Global observations of aerosol-cloud-radiation and aerosol-cloud-precipitation-convection processes.

Vertical profiles to derive instantaneous radiative flux with an accuracy of 10 W m^{-2}

Scientific Justification

The climate and weather forecasting problem (1/2)

There is a need to quantify aerosol-cloud-radiation interactions in order to correctly represent them in climate and weather forecasting models.

a) aerosols and radiation

- direct cooling by blocking sunlight
- absorbing aerosols (e.g. carbon) lead to heating

Can we quantify these direct aerosol effects?

b) aerosols and clouds

- aerosols act as cloud condensation nuclei
- more aerosol lead to more reflective cloud and less precipitation

Can we quantify these indirect aerosol effects?

Scientific Justification

The climate and weather forecasting problem (2/2)

c) clouds radiation and climate

- more low clouds reflecting sunlight → cooling
- more high (cold) clouds, less IR to space → warming
- Cloud feedbacks dominate the sensitivity of climate to external forcing but existing models do not even agree on their sign (IPCC 2001).

Do current models have the correct vertical structure, overlap, amount of condensate, sedimentation rate of ice (i.e. cirrus lifetime) ?

d) convection and precipitation

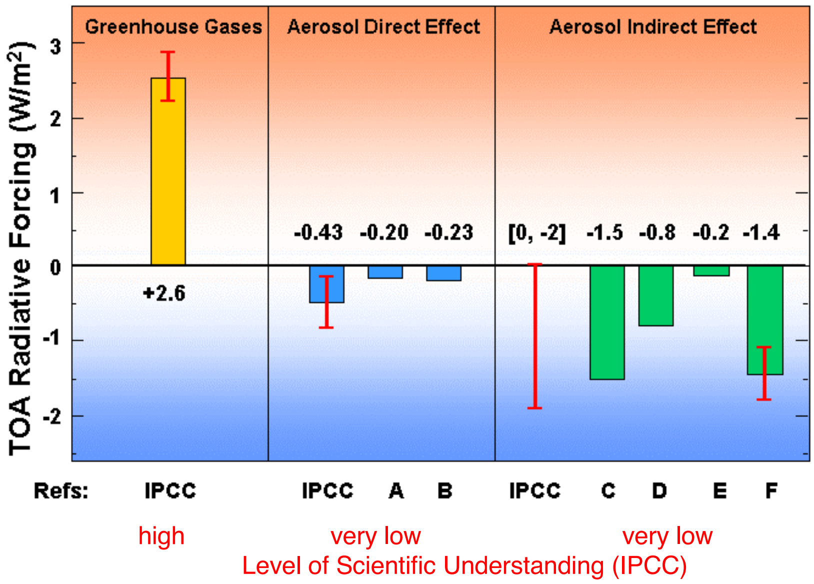
- Convective precipitation (crucial for flash floods and aerosol transport) is produced by sub-grid-scale vertical motions of cloud condensate.
- Passive satellite observations suggest 0.5% of convection penetrates cold trap into stratosphere.

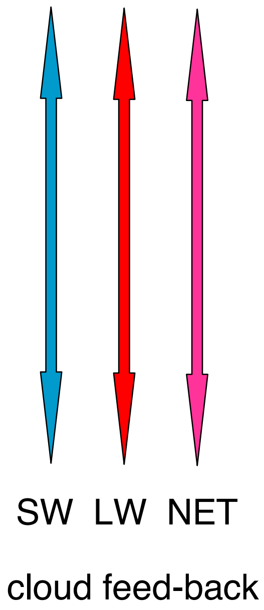
Are these parameterised motions correct?

How much moisture does convection introduce into the stratosphere?

Scientific Justification

Climate – Forcing Changes 1750 to 2000





Recent work:

- Reduced uncertainty for direct aerosol effect on radiation
- Still very large uncertainty on indirect effect on clouds (albedo and lifetime) and any effect on ice clouds still unknown.

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Scientific Justification

Parameterisation in Forecasting and Climate Models

- **Not possible** to represent **individual clouds** in global models.
- Typical grid-box size is 40-200 km (horizontal) and ≈0.5 km (vertical).
- Typical variables in each grid-box:
  - **fractional cloud cover (plus crucial overlap assumptions)**
  - **Ice Water Content (IWC) and Liquid Water Content (LWC)**
  - **cloud particle size, shape and fall velocity**
  - **aerosol, mass, size and composition.**
- There is a large disparity of values of the above variables between different models.

Model Evaluation – in practice:

NO global information on the vertical profiles of aerosols

NO reliable profiles of ice water content are available

NO observations on global characteristics of convective updraughts

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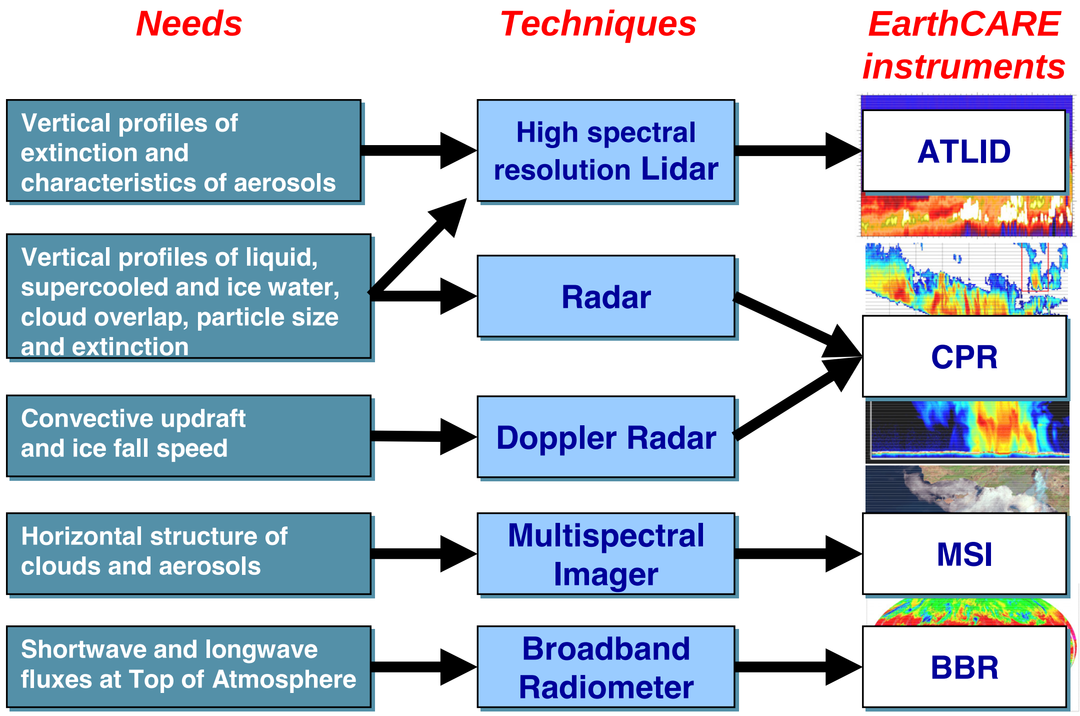
Observation Technique

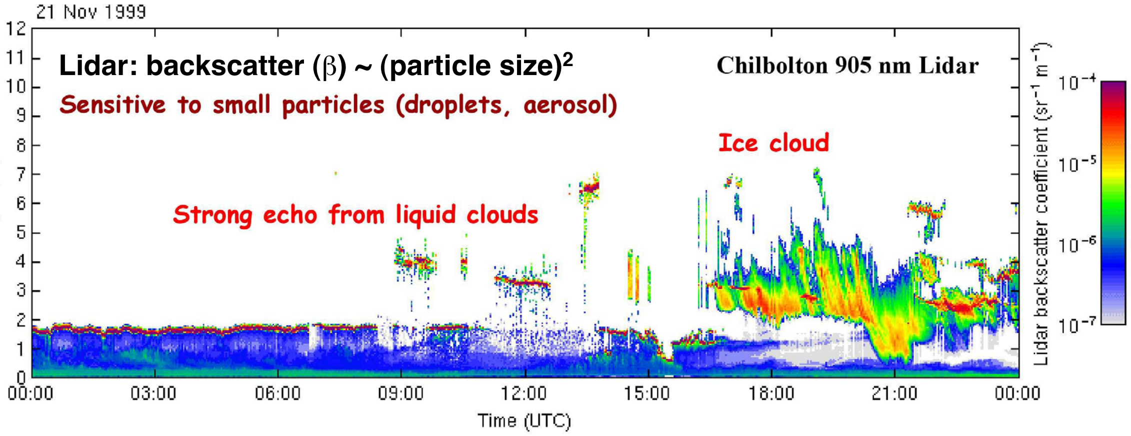
Mission Concept



Temperature and humidity from operational analysis

Observation Technique

Backscatter Lidar



Requirement: backscatter sensitivity of $8 \cdot 10^{-7}$ m^{-1} sr^{-1} to detect radiatively significant clouds or aerosols (extinction coefficient α larger than 0.04 km^{-1})

Problems: (a) correcting for lidar attenuation is very difficult

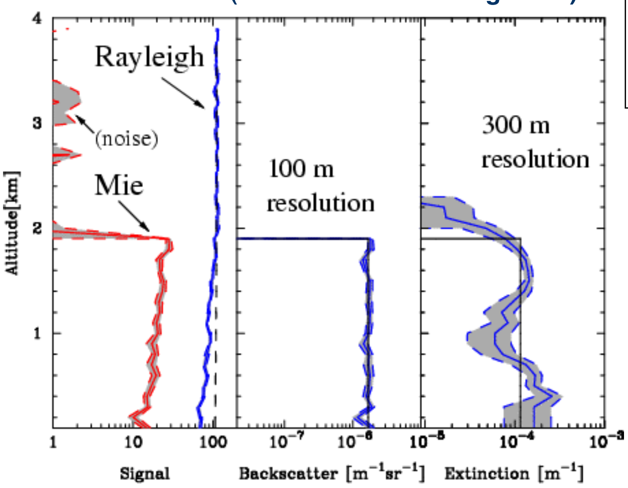
(b) converting lidar backscatter to extinction is ambiguous

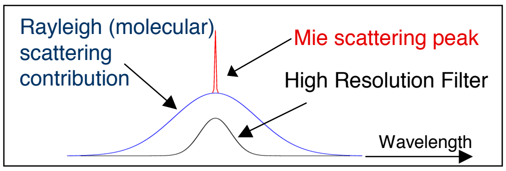
Solution: High Spectral Resolution to separate molecular (Rayleigh) and cloud/aerosol (Mie) scattering

Observation Technique

High Spectral Resolution 355 nm Lidar

PBL Aerosol (10 km horizontal integration)





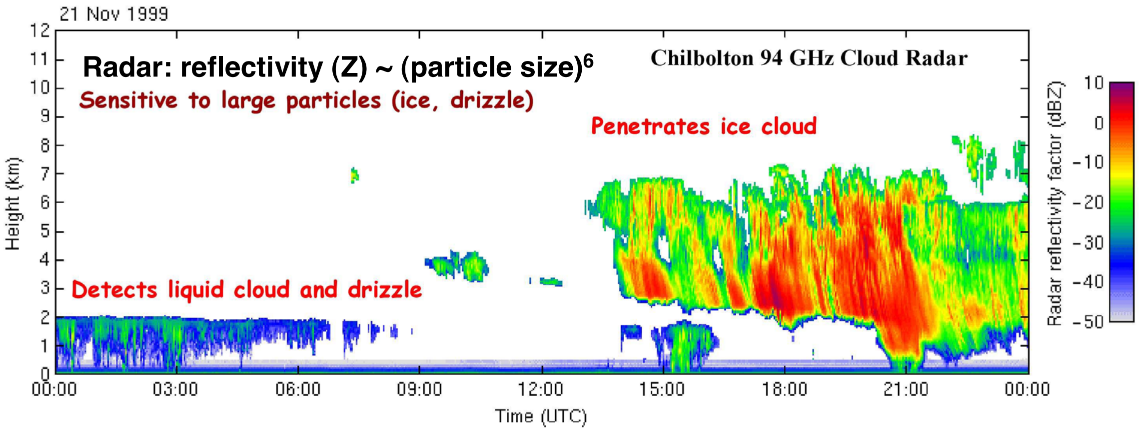
1. **Compare observed molecular return with expected non-attenuated value**
   ⇨ True extinction coefficient (α) and/or optical depth (τ)
2. **Use α to correct the attenuated backscatter (β_{OBS}) ⇨ (β_{TRUE})**
3. **Derive the true lidar ratio α/β ice crystal habit and aerosol size / composition**

Additional information:

Shape of ice particles and aerosols: from cross-polarisation channel

Distinguish anthropogenic from natural aerosol: from cross-polarisation channel and lidar ratio

Observation Technique
Radar



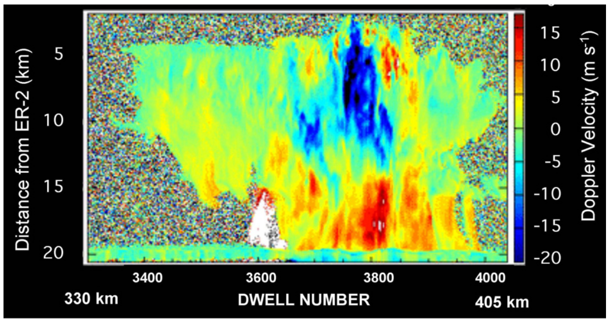
Requirements: reflectivity threshold of –36 dBZ detects 98 % of the radiatively significant ice clouds (10 km horizontal integration; 400 m vertical resolution)

Retrieval Accuracy:

IWC retrieval from radar alone:	50 % - 100 % error
IWC retrieval radar+lidar:	30 % error
Extinction profile radar+lidar:	10 % error

Observation Technique
Doppler Radar

Aircraft overflying severe tropical convection with downward looking Doppler radar.

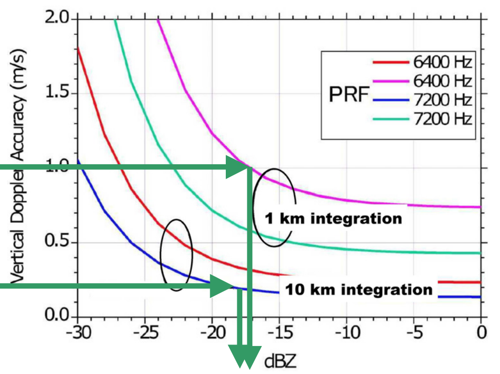


- Observing overshooting of convection and water mass flux into stratosphere
- Measuring Ice sedimentation rate (cirrus lifetime)
- Measuring light precipitation

Doppler Requirements:

Accuracy for

- Convective motion: 1 m/s
- Ice fall speed: 0.2 m/s
- Drizzle rate: 0.2 m/s



reflectivity threshold of –18 dBZ detects 96 % of the ice mass flux

Observation Technique

Passive measurements

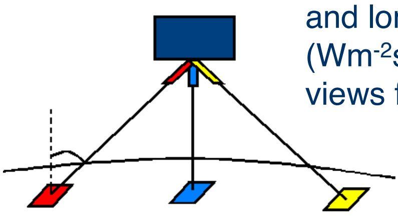
Multi-spectral imager (MSI)

Imaging a 150 km swath with 7 channels from visible (0.6 μm) to the thermal infrared (12.0 μm) and 500 m resolution

→

Cloud types
Ice/Water phase
Cloud optical thickness
Effective radius
Aerosol optical thickness
Surface reflectance
Surface temperature

Broadband radiometer (BBR)



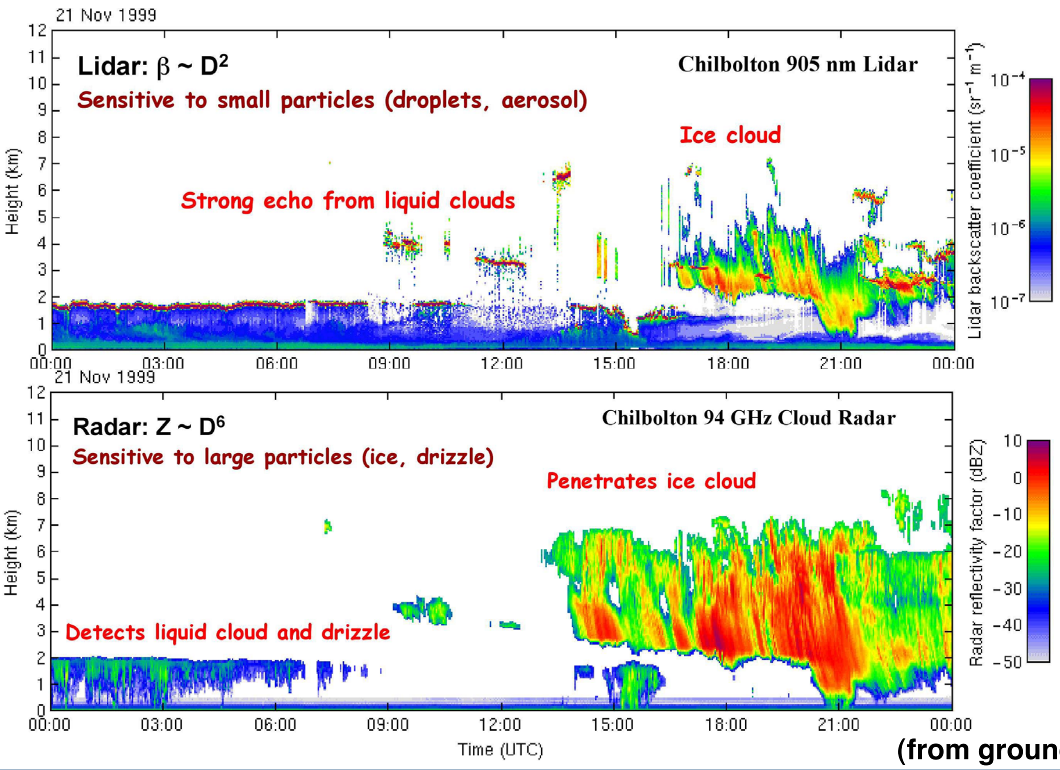
Measuring broadband short- and longwave radiances ($Wm^{-2}sr^{-1}$) with 3 along-track views for 10 km pixels

→

Instantaneous
SW, LW flux

Observation Technique

Synergy: Lidar and Radar combination



(from ground)

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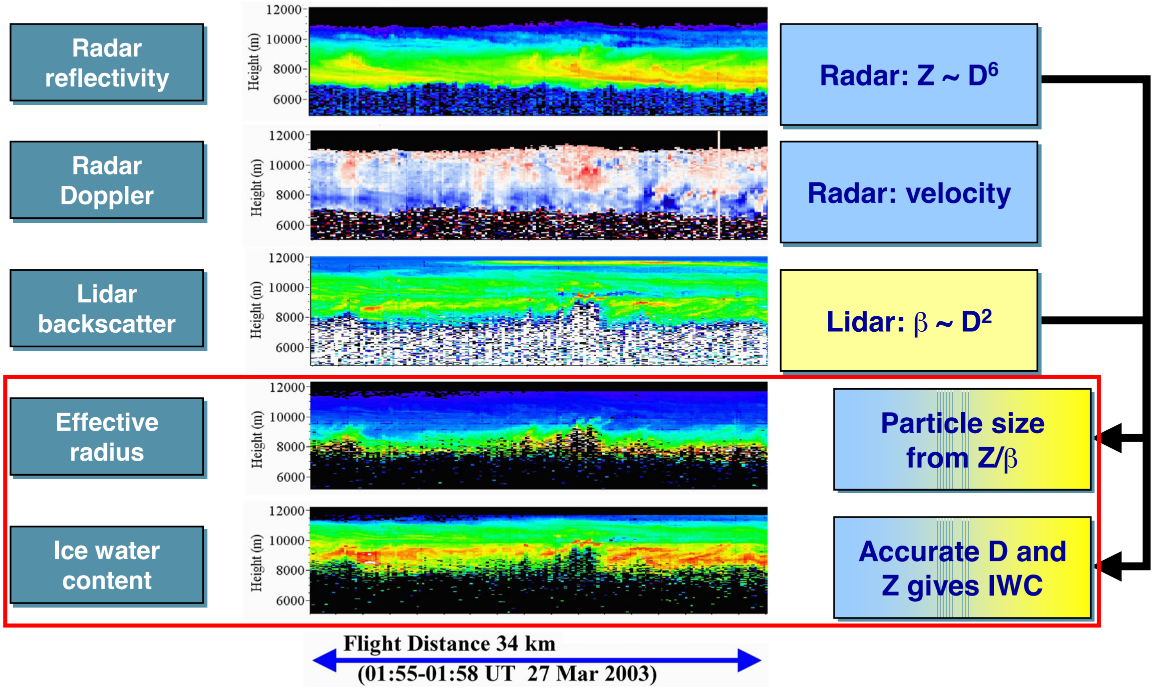
Observation Technique

Synergy: Lidar and Radar combination (from aircraft)

APEX/ECAV 2003, Japan



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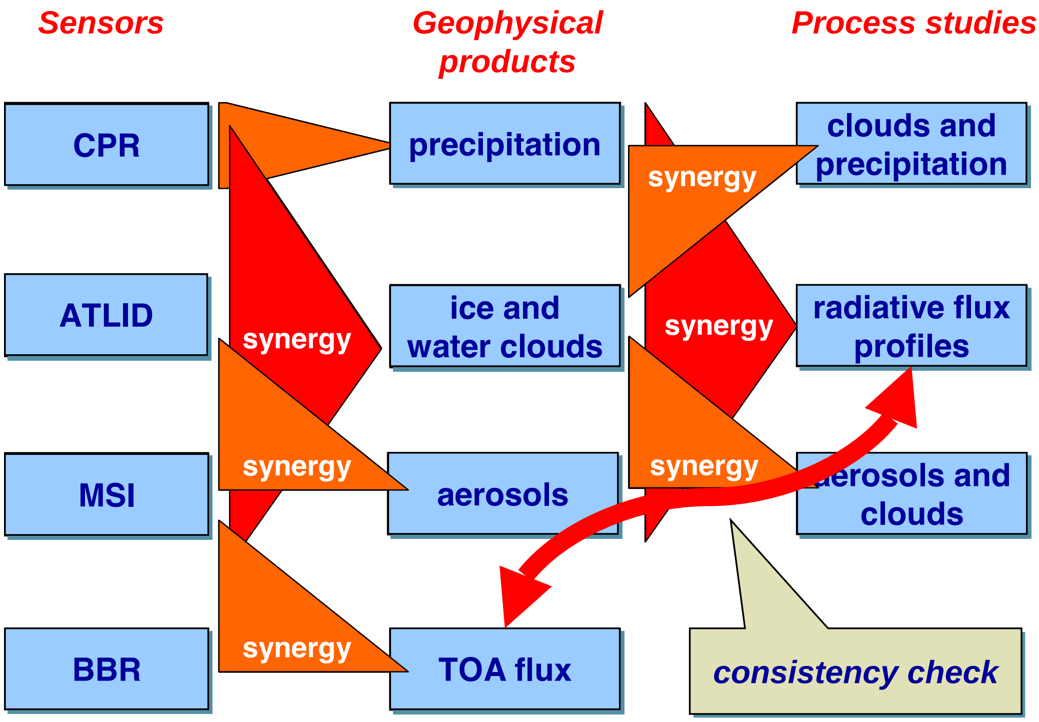
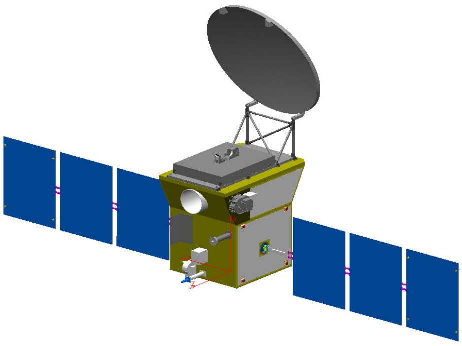
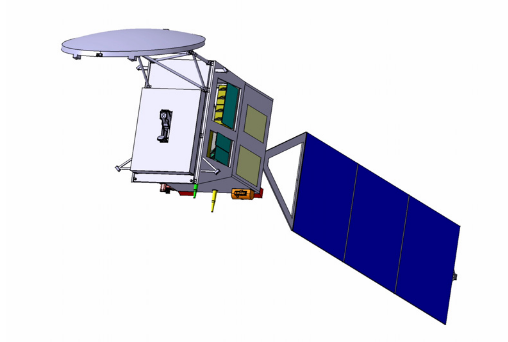
Observation Technique

Synergy



System Overview





SPACE SEGMENT

Payload:
- Backscatter Lidar (ATLID)
- Cloud Profiling Radar (CPR)
- Multi-Spectral Imager (MSI)
- Broad-Band Radiometer (BBR)

Platform

MISSION PARAMETERS

Orbit:
- Sun-synchronous
- Altitude 450.8 or 443.8 km
- Local time 10:30 descending node
- Repeat cycle 11days (15+4/11) or 31 days (15+12/31)

Launch date: Mid 2011

Mission life: 2 years (+1 yr or 15 % additional Propellant)

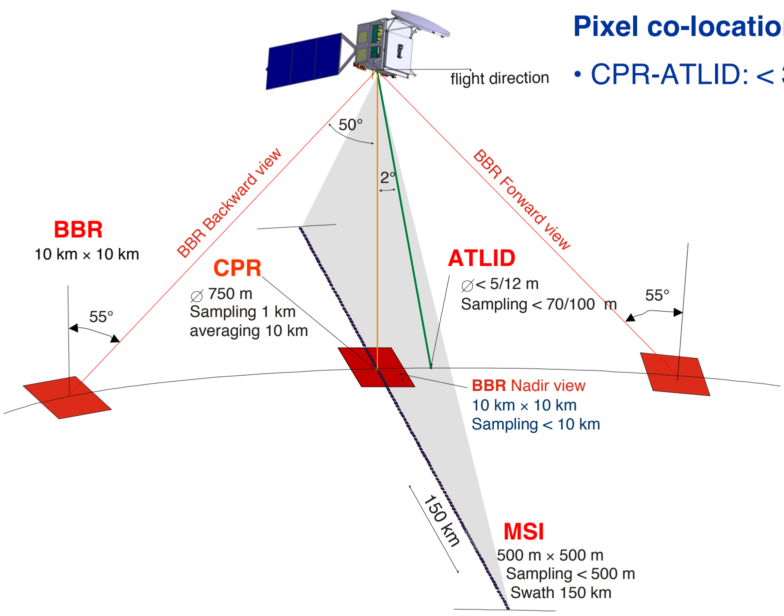
LAUNCH VEHICLE OPTIONS
- PSLV
- DNEPR
- SOYUZ

GROUND SEGMENT
- CDAE in Kiruna
- MSCE at ESOC
- PAE in ESRIN and Japan

Instrument viewing geometry

Time difference between acquisitions:
- CPR-ATLID: 2.2 s
- BBR nadir - fw/bw: 77 s

Pixel co-location:
- CPR-ATLID: < 350 m RMS



ATLID Requirements

3 channels:

– Mie scattering co-polar channel

– Mie scattering cross-polar channel

– Rayleigh scattering channel

• Instrument sized to detect the weak signal from the thinnest radiatively significant cirrus cloud in daytime above dense cloud deck

		Mie co-polar channel	Rayleigh channel	Mie cross-polar channel
Cirrus	Cirrus optical depth	0.04		
	Backscatter sr^{-1} m^{-1}	8×10^{-7}		2.6×10^{-5}
Vertical resolution		100 m	300 m	100 m
Required accuracy	@ 10 km integration	50 %	15 %	50 %

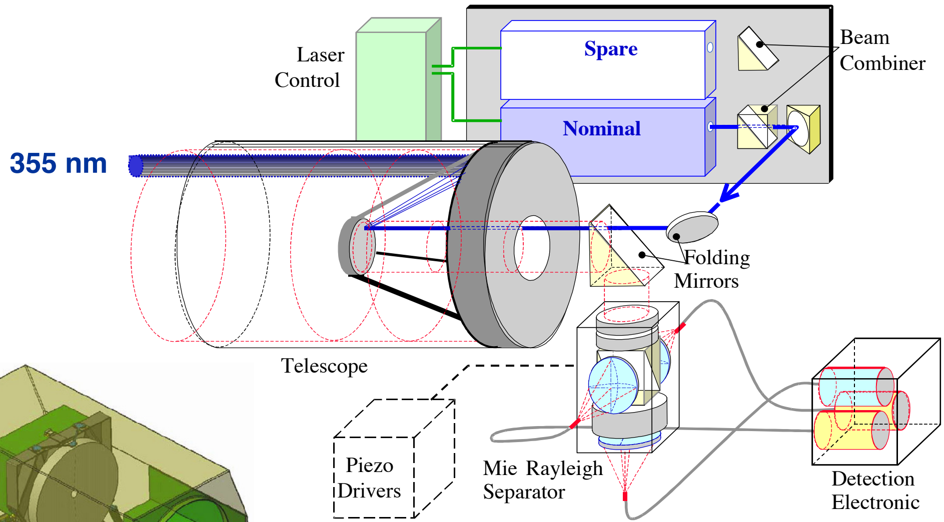
• Altitude range: -0.5 to 30 km

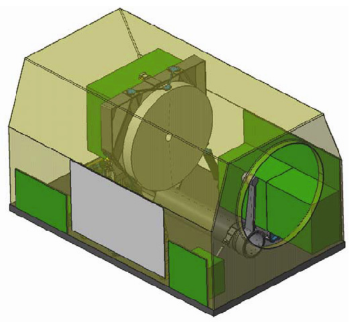
• Horizontal sampling interval: < 100 m

• Vertical sampling interval: 100 m below 20 km altitude, 500 m above

ATLID Configuration

A UV backscatter lidar with High Spectral Resolution Receiver





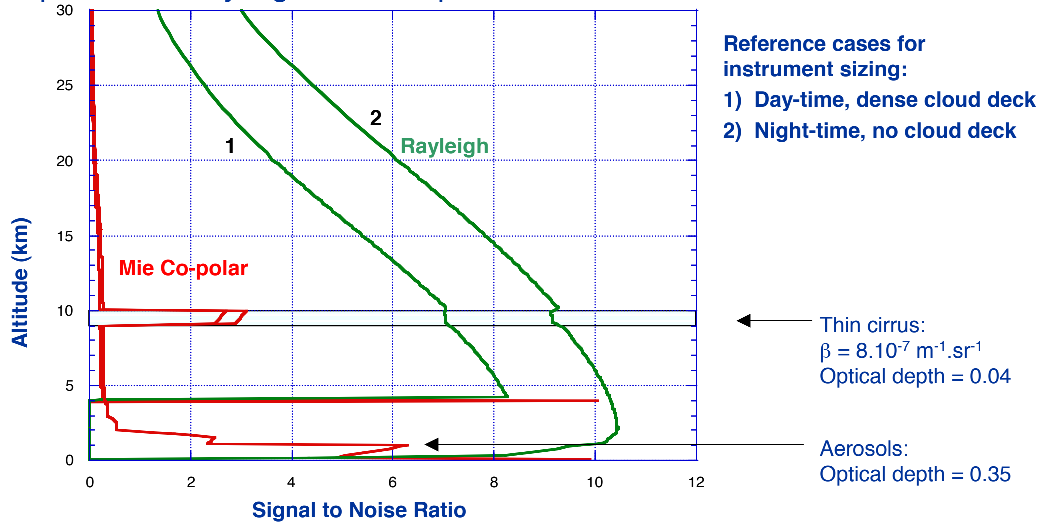
Mass: < 230 kg

Power: < 308 W

Data rate: < 822 kb/s

ATLID Performance Summary

Mie co-polar and Rayleigh channel performance

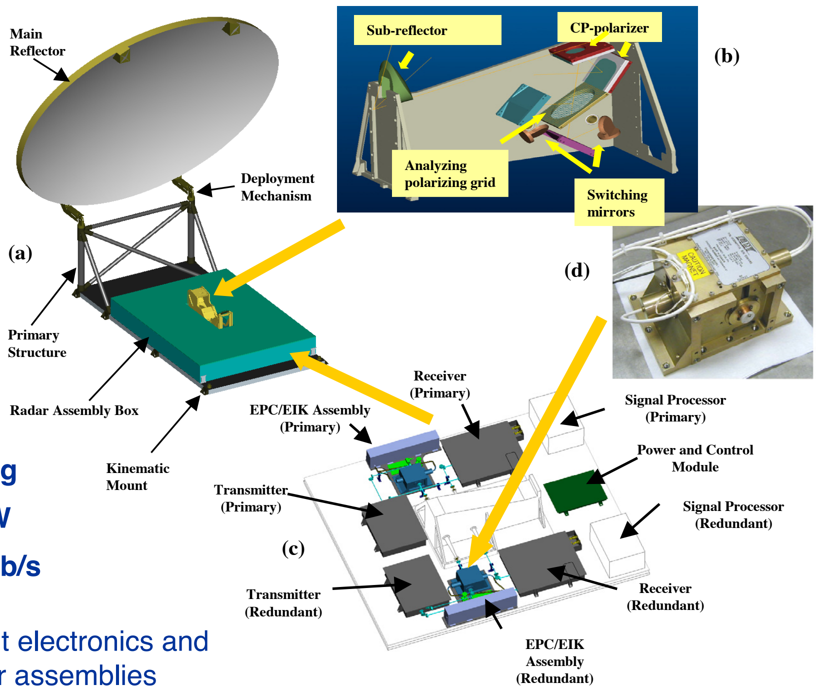


Optical depth retrieval performance

	Performance
Cloud layer, τ = 1	< 24%
PBL aerosol (1 km vertical integration)	$\frac{\partial Ray_{inp}}{Ray_{inp}}$: 8 to 16%

Cloud Profiling Radar

- Provided by NICT JAXA -



Mass: **216 kg**

Power: **300 W**

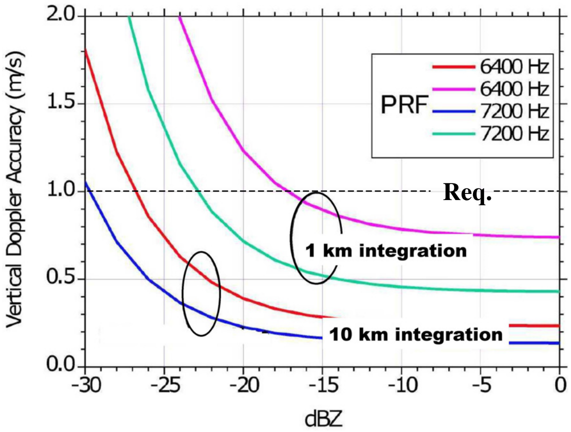
Data rate: **120 kb/s**

Fully redundant electronics and power amplifier assemblies

CPR Requirements & Performance

Centre Frequency:	**94.05 GHz**
Footprint diameter:	**750 m**
Measurement range:	**-0.5 km – 20 km (12 km)**
Vertical resolution:	**400 m (100 m sampling)**
Along-track sampling:	**1 km (900 – 1000 pulses averaged)**
Sensitivity:	**≤ -36 dBZ at TOA (10 km integration)**
Doppler accuracy:	**≤ 1 m/s (see below)**

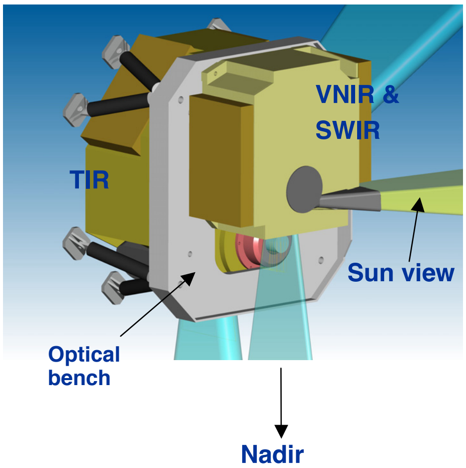
Doppler vs. reflectivity

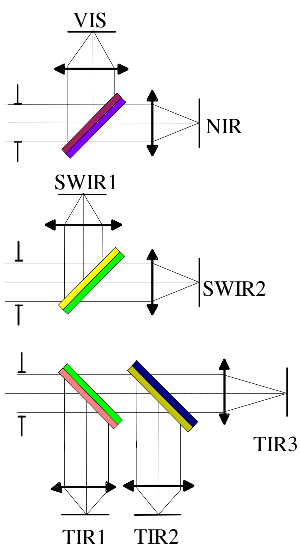


Pulse Repetition Frequency:
~ 6400 Hz within ± 60° latitude
~ 7200 Hz beyond ± 60°

MSI Configuration

- Pushbroom imager
- One camera for each sub spectral range (VNIR, SWIR and TIR)
- Dichroics separation with 0.1 pixel co-registration
- Calibration:
  VNIR & SWIR: dark level and solar diffuser panel
  TIR: Cold space and on board black-body (300 K)

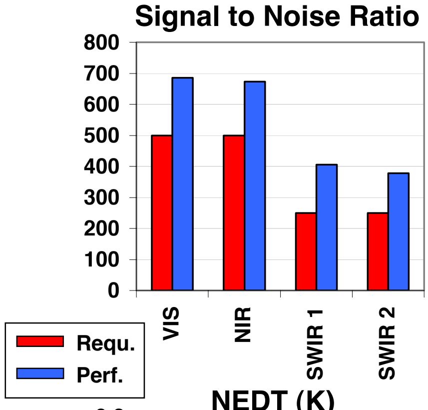


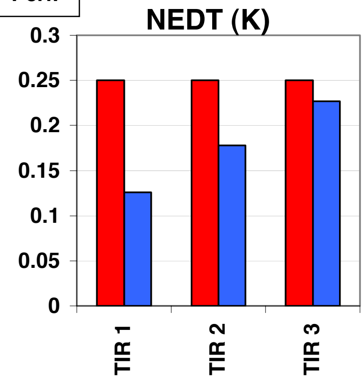


Mass:	**< 31 kg**
Power:	**< 86 W**
Data rate:	**< 515 kb/s**

MSI Performance

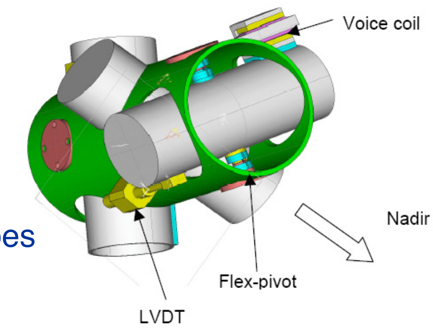
Parameter		Requirement	
Swath		150 km	
Footprint		500 m	
Spectral channels		Centre (μm)	Width (μm)
	VIS	0.659	0.02
	NIR	0.865	0.02
	SWIR 1	1.61	0.06
	SWIR 2	2.2	0.1
	TIR 1	8.8	0.9
	TIR 2	10.8	0.9
	TIR 3	12.0	0.9
Radiometric resolution	VIS/NIR	SNR > 500	at ρ = 1.0
	SWIR	SNR > 250	
	TIR	NEDT < 0.25 K at 293 K	

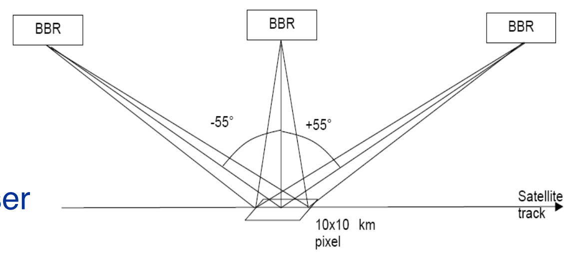




BBR Configuration

- Along track sampling: 3 telescopes
- Telescope zenith angle: θ = 0°, ± 55°
- Pixel : - 10 km x 10 km for all three telescopes
  - 0.1 pixel co-registration
- Two spectral channels:
  - SW: 0.2 - 4.0 μm
  - LW: 4.0 - 50 μm
- Calibration:
  - Sun calibration via diffuser
  - Deep space calibration
  - Black body calibration
- Parallax compensation by over-sampling

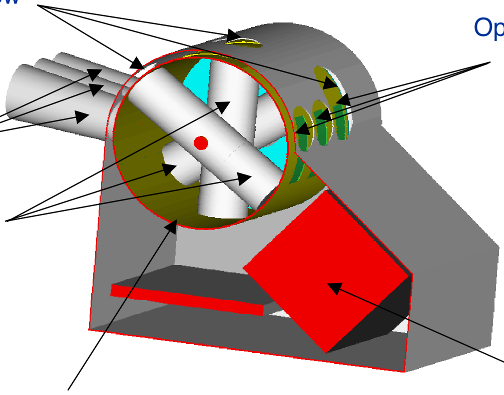




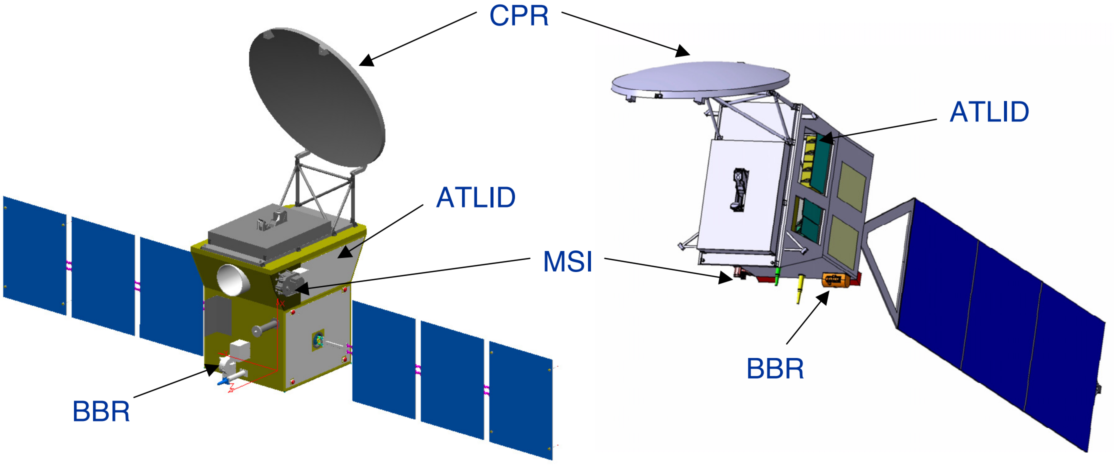
Mass: < 27 kg
Power: < 43 W
Data rate: < 50 kb/s

BBR Performance

Flux accuracy (SW Channel)	1σ value W.m^{-2}
Instrument	7.20
Unfiltering	2.60
Flux retrieval	4.00
Total RMS	8.7

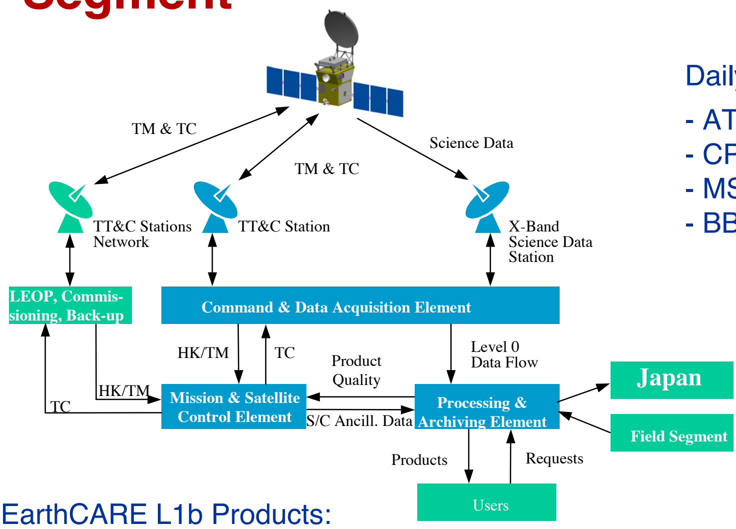


Satellite Configuration



Mass:	**1238 kg**	**Mass:**	**1318 kg**
Power:	**1068 W**	**Power:**	**1119 W**
Data rate:	**914 kb/s**	**Data rate:**	**1511 kb/s**

Ground Segment



Daily data volume: 19.2 GB

- ATLID: 12.0 GB
- CPR: 1.3 GB
- MSI: 5.3 GB
- BBR: 0.6 GB

EarthCARE L1b Products:

ATLID
- Rayleigh profiles
- Mie profiles
- Depolarisation profiles

CPR
- Reflectivity profiles
- Doppler profiles
- Doppler spectral width profiles

MSI
- Radiances in all 7 channels

BBR
- Radiances in all 6 channels

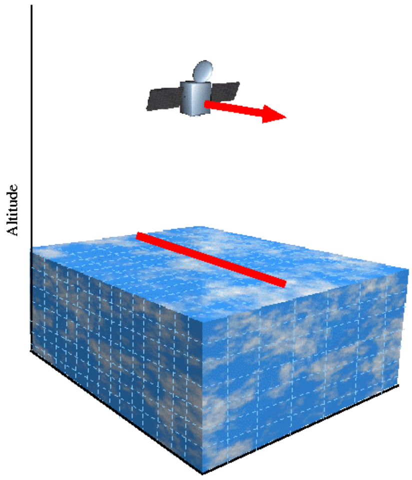
Data delivery at level 1b within about 12 hrs from reception.

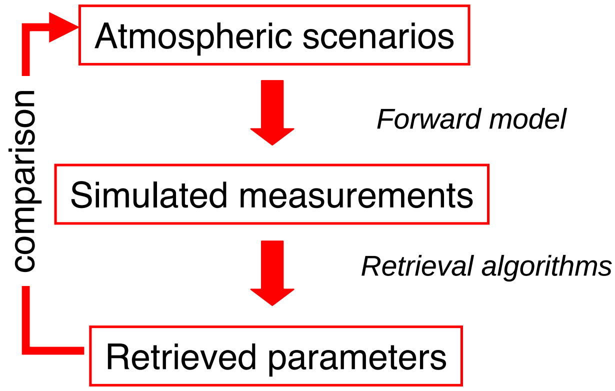
Technical Summary

- Two satellite concepts that meet the mission requirements
- Instruments provided with high degree of internal redundancy to preserve instrument synergy
- Extensive heritage from running projects
- No critical units in satellite concepts
- Readily available launch vehicles
- Reuse of the Agency's existing infrastructure for the ground segment
- Taking into account the above elements, a launch in 2011 can be considered

Mission Performance
Scientific performance studies

- **Algorithm validation and comparison activities (lidar+radar blind tests)**
- **Supporting Campaigns (CLARE'98, APEX/ECAV 2003) and**
- **Development of an EarthCARE End-to-End Simulator:**

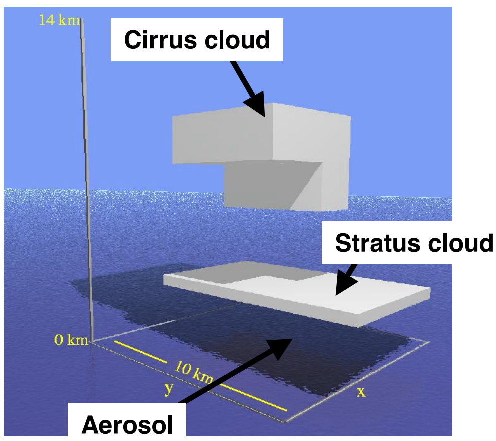




Mission Performance
EarthCARE Simulator

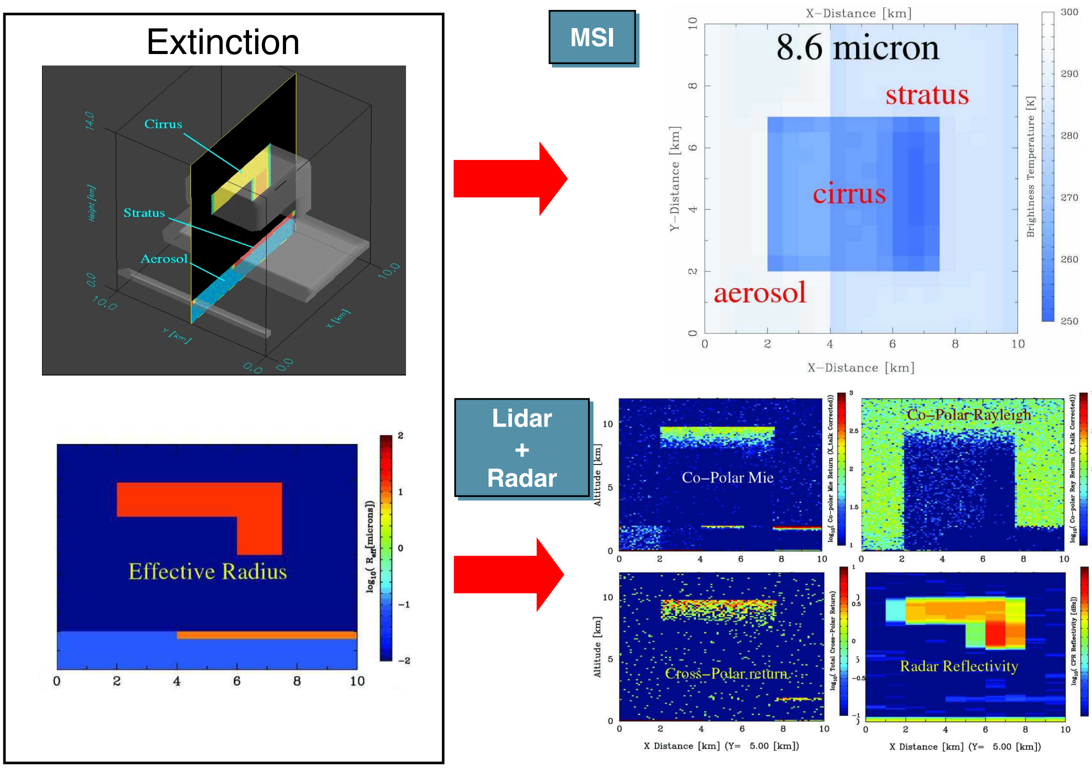
- Simple scenes or complex scenes with highly detailed cloud and aerosol microphysics
- Resolution down to 25 m
- 3-dimensional Monte-Carlo radiative transfer code for long- and short-wave radiation including multiple scattering (also for lidar)
- Instrument characteristics including noise, sampling and footprints
- Retrieval algorithms implemented

Example of 'simple' scene (scale of BBR footprint)



Mission Performance

EarthCARE Simulator - Example atmospheric scene

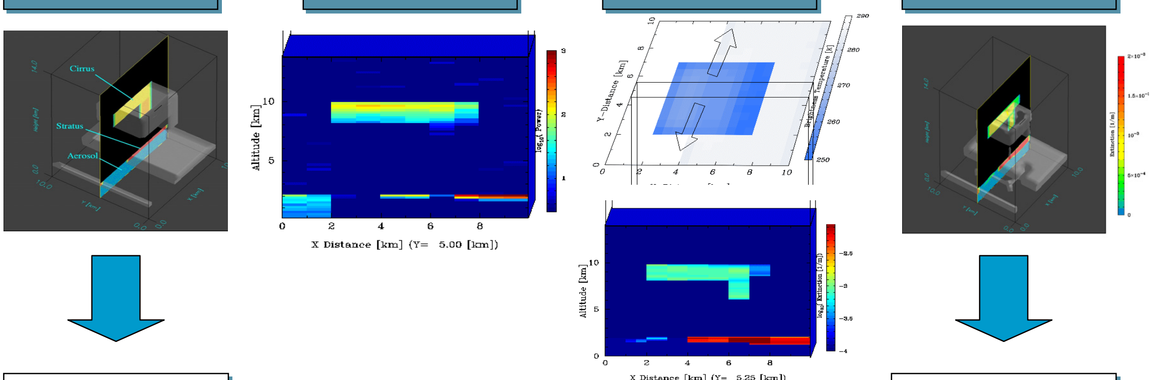


Mission performance

EarthCARE simulator: Putting the pieces together

MSI image

synthetic 3D scene — extinction → simulated measurements — co-polar Mie → Retrieval profiles — extinction → reconstructed 3D scene — extinction



LW radiation (TOA): 238.6 W/m²

Difference :
2.3 W / m² < 10 W / m²

LW radiation (TOA): 236.3 W/m²

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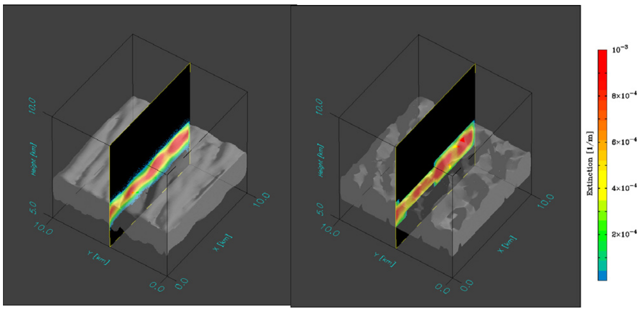
Mission Performance

EarthCARE Simulator: Complex cloud scene

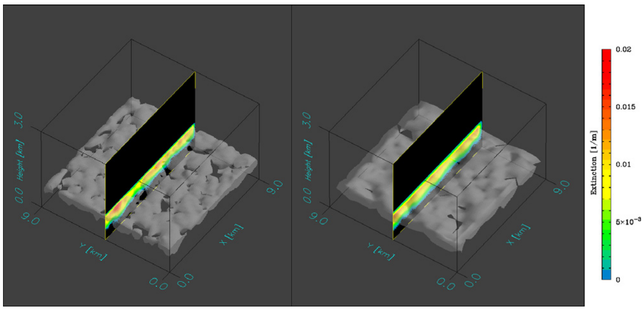
model 3D scene   reconstructed scene



thin cirrus case

	True	Retrieved
SW TOA (W/m^2)	*116.0*	*121.0*
LW TOA (W/m^2)	*206.5*	*213.0*

Differences: SW TOA 5 W/m^2 ; LW TOA 6.5 W/m^2



stratus case

	True	Retrieved
SW TOA (W/m^2)	*286.0*	*290.0*
LW TOA (W/m^2)	*274.9*	*273.9*

Differences: SW TOA 4 W/m^2 ; LW TOA 1 W/m^2

10 W/m^2 is an achievable goal !!

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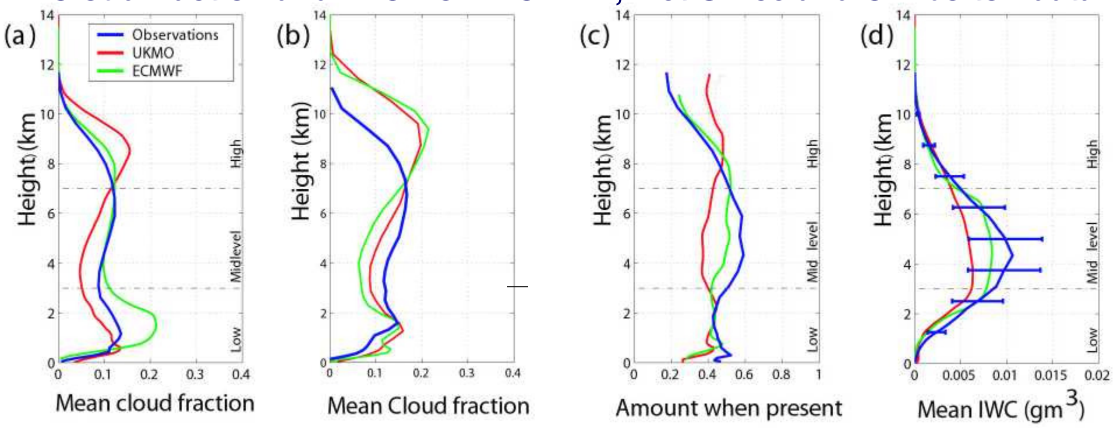
User Readiness

Evaluation of model skills

Cloud fraction and IWC from ECMWF, Met Office and Chilbolton data



May 1999 – May 2000   Apr 2003 – Oct 2003   May 1999 – May 2000   May 1999 – May 2000

- Cloud occurrence relatively good
- Models generate too many clouds above 6 km.
- ECMWF 2003 scheme: now improved for low clouds

Need global statistics

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User Readiness

Assimilation in Forecasting Models

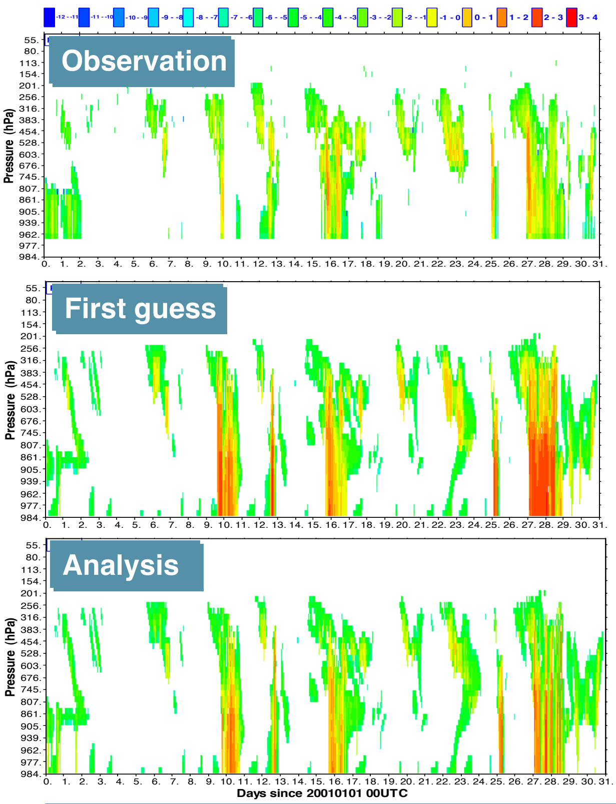
- Atmospheric models require accurate initial conditions
- Data assimilation involves combining the model first guess and observations to provide these initial conditions
- Clouds are intimately linked to the dynamic and thermodynamic evolution of the atmosphere
- Despite the importance of clouds and precipitation in the atmosphere, there is no *explicit* analysis of clouds in *global* data assimilation systems

Inclusion of cloud related observations is *essential* to improve forecasts

esa Earth Explorers The Living Planet Programme European Space Agency

User readiness

ECMWF Data Assimilation of Radar Data



January 2001:

Observations from ARM's (Atmospheric Radiation Measurement) 35 GHz cloud radar in Oklahoma.

First guess

Improved analysis after 1D-Var assimilation combining the first guess model data and the radar observations.

Benedetti and Janisková (2004)

Other Space Missions

ICESAT (GLAS lidar) – launched in January 2003
- ice altimetry mission - will also see clouds
- lidar alone - cloud measurements are difficult to interpret

Calipso-CENA (lidar) - launch 2005
- flying in formation with CloudSat, EOS-AQUA, EOS-AURA, and Parasol
- EarthCARE single platform ensuring lidar/radar synergy
- EarthCARE has high spectral resolution lidar

CloudSat (radar) - launch 2005
- very good demonstration of radar retrievals from space
- EarthCARE radar is almost 10 times more sensitive.
- EarthCARE has Doppler capability

EarthCARE is the second generation cloud and aerosol mission
CloudSat/Calipso will be excellent demonstrators for EarthCARE

International Context

- WCRP (World Climate Research Programme)
  - GEWEX (Global Energy and Water Experiment) with
    - GRP (GEWEX Radiation Panel)
    - ISCCP (International Satellite Cloud Climatology Project)
    - GACP (Global Aerosol Climatology Project)
  - SPARC (Stratospheric Processes And their Role in Climate)
- WMO (World Meteorological Organisation)
  - WWW (World Weather Watch)
  - GOS (Global Observing System)
- GCOS (Global Climate Observing System)
- …

Applications

Improvement in climate and weather forecasting models through the correct representation of aerosol-cloud-radiation-precipitation interactions by quantifying the following:

- Direct and indirect aerosol effect
- Cloud-radiation feed-back
- Convection and precipitation mechanisms
- Convective ice mass flux into the stratosphere

Supplying data for use in operational NWP data assimilation

In addition

Aerosol horizontal and vertical transport and source identification

- assessment of anthropogenic aerosols
- monitoring polar aerosols and clouds

Role of cloud and aerosol in atmospheric chemistry

Improvement of retrievals based on passive satellite measurements

Improvement of existing data sets, e.g. ISCCP, ARM, AERONET,…

Summary

- Aerosols control cloud properties, clouds control the production of precipitation, vigorous convection influences stratospheric humidity.
- Cloud feedbacks are the main cause of the uncertainty in predictions of future climate.
- Correct representation of clouds – aerosol – radiation processes in models (NWP and climate) is needed. Current knowledge of the global profiles of aerosol and cloud properties is far too limited.
- Required profiles can only be provided by High Spectral Resolution lidar and Doppler cloud radar embarked upon the same satellite
- Active instruments together with MSI and BBR constrain radiative flux profiles to 10 W / m^2

EarthCARE observations will lead to more reliable climate predictions and better weather forecasts through the improved representation of processes involving clouds, aerosol and radiation.