Handouts

EOPP Seminar on Radiation Studies

1 September 1998

ESTEC, Noordwijk, The Netherlands

esa

Contents

IIIB Lidar Concepts and Technologies

IIIC Passive Sensor Concepts and Technologies

IV The Plans

INTRODUCTION

A. TOBIAS, ESA, EOPP

EOPP SEMINAR ON RADIATION STUDIES

Introduction

1. Scope
2. Background on the ERM

1. SCOPE

- The seminar will present the main results of the recent studies related to the Earth Explorer Earth Radiation mission (ERM)

- It is not possible to present all the Radiation related studies. Activities not presented are:

    - Scientific mission definition studies financed by the General Studies Programme to define the long term future (ERB, ERM)

    - Mission concepts, e.g. the polar and geostationary operational meteorological systems (Met***Op*** and MSG) are essential for the ERM and have been studied under EOPP; or the GETEM a GERB based Earth Radiation Budget mission concept also studied under EOPP. They are not presented.

    - Instruments: utilisation of SCARAB on ENVISAT and Met***Op*** (at the end not provided), MIMR, GERB, ... are not presented

    - Technology and support: only recent activities

- The activities presented are mainly EOPP financed but also ERM related activities financed by the General Studies Programme (GSP) and the Technology Research and Development Programme (TRP and GSTP) are included.

Agenda

I. THE UNDERLYING SCIENCE

- Introduction *(ESA)*
- Synergy study *(University Quebec)*
- Cloud and Radiation "CLARA" analysis *(KNMI)*

Coffee break

- Cloud radar critical requirements *(GKSS)*
- Cloud radar critical requirements *(Univ Reading)*

II. SYSTEM

- Introduction *(ESA)*
- System concepts *(MMS-F)*

Lunch break

III. TECHNOLOGY AND SUPPORT

A. Cloud Profiling Radar (CPR) concepts and technologies
- Introduction *(ESA)*
- CPR concept study *(DSS)*
- CPR concept study *(Alcatel)*

Coffee break

B. Lidar concepts and technologies

Introduction *(ESA)*
Laser head critical technology *(Alenia Difesa)*
Filter, detection chain critical technology *(MMS-F)*

C. Passive sensors concepts and technologies
- Introduction *(ESA)*
- Cloud imager concepts (Officine Galileo)
- Broadband radiometer concepts *(REOSC)*

IV. The plans

- Earth Explorer Earth Radiation Mission, phase A activity plan *(ESA)*

2. BACKGROUND ON THE ERM

- The Earth Explorer Earth Radiation Mission was part of an initial set of nine candidates proposed for the first round of Earth Explorer core missions:

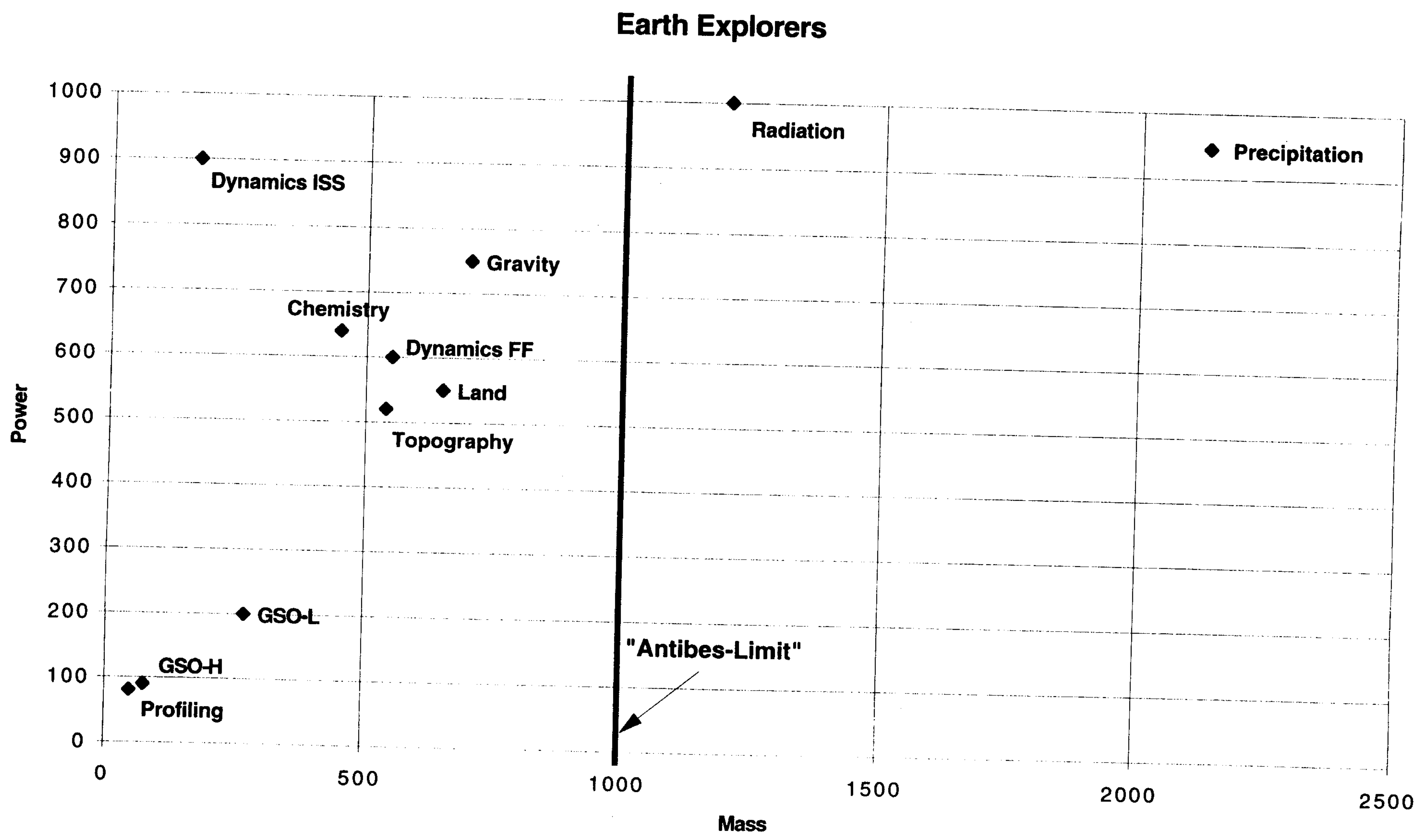
- ***The Earth Radiation Mission (ERM)***
- *The Gravity field and steady-state Ocean Circulation (GOCE)*
- *The Land-Surface Processes and Interactions Mission (LSPIM)*
- *The Atmospheric Dynamics Mission (ADM)*
- The Atmospheric Chemistry Mission
- The Magnetometry Mission
- The Precitipation Mission
- The Atmospheric Profiling Mission
- The Topography Mission

- In the first selection attempt, Earth Observation User Consultation Meeting 1994, the ERM was included in a shortlist with GOCE and LSPIM for study at phase A level. The process had to be stopped.

- Second attempt, assessment (1995-1996), Earth Explorer User Consultation Meeting 1996, review by ESAC and peer review groups. Recommendation for 4 candidates: ERM, GOCE, LSPIM and ADM for study at phase A level approved by PB/EO. ... But start of phase A delayed because of slow subscription to EOPP

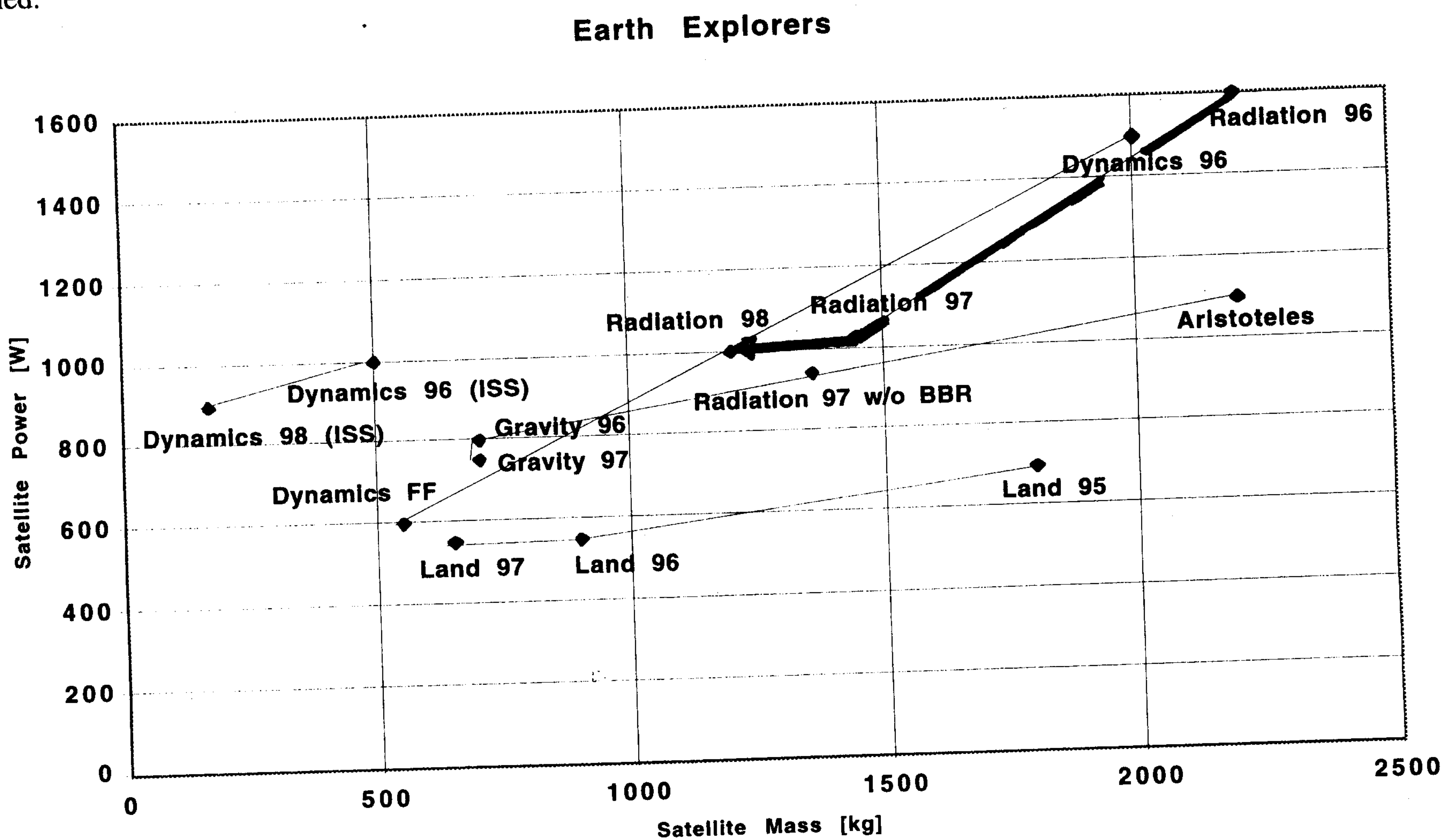
- ITT for phase A study finally released in November 1997. Proposals February 1998. Evaluation March 1998. Contract proposal approved by IPC 30 June 1998. Kick-off, 3 July 1998.

2. BACKGROUND ON THE ERM



2. BACKGROUND ON THE ERM

The 3 year period since first selection of ERM until the actual start of the phase A has not been lost but used to refine the ERM mission / system concept with the resources available. Other candidate Earth Explorer missions have also been refined.



2. BACKGROUND ON THE ERM

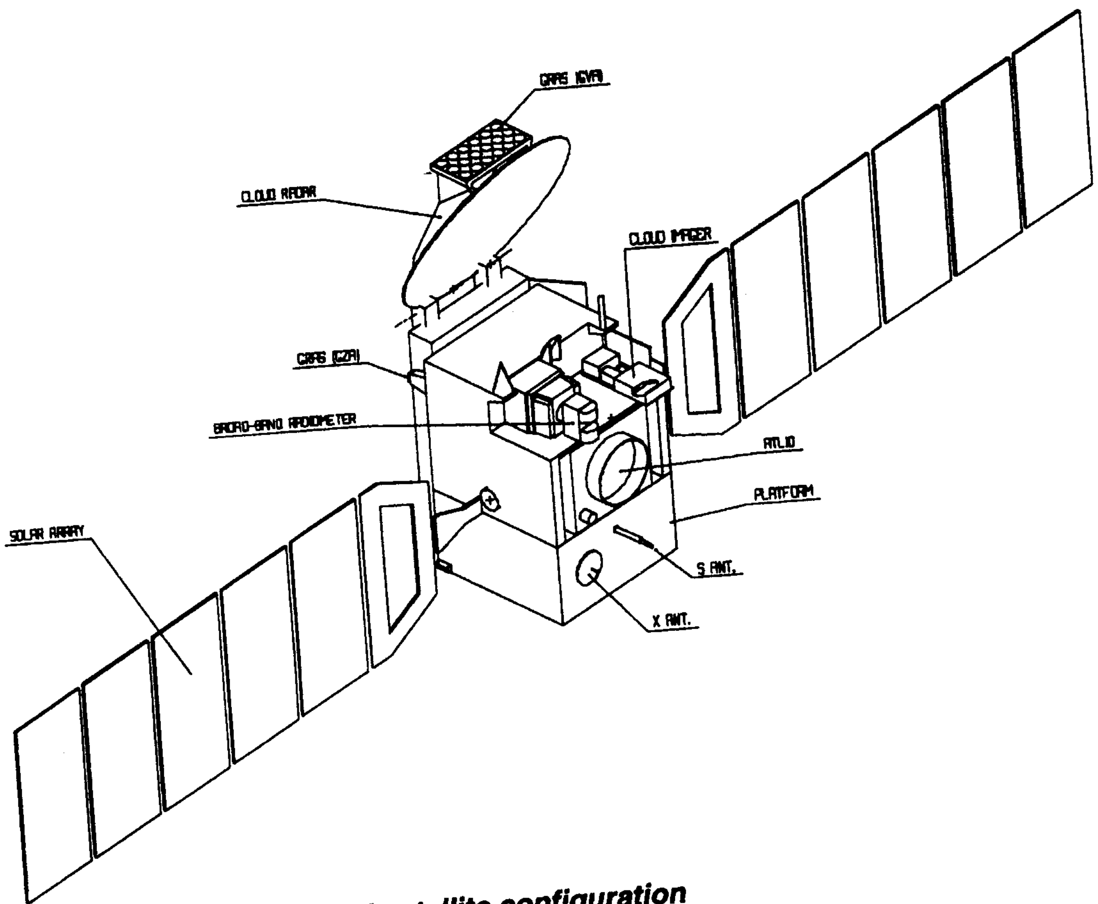
- The ERM is one of the candidates to become the first Earth Explorer core missions.

- The ERM mission elements are:

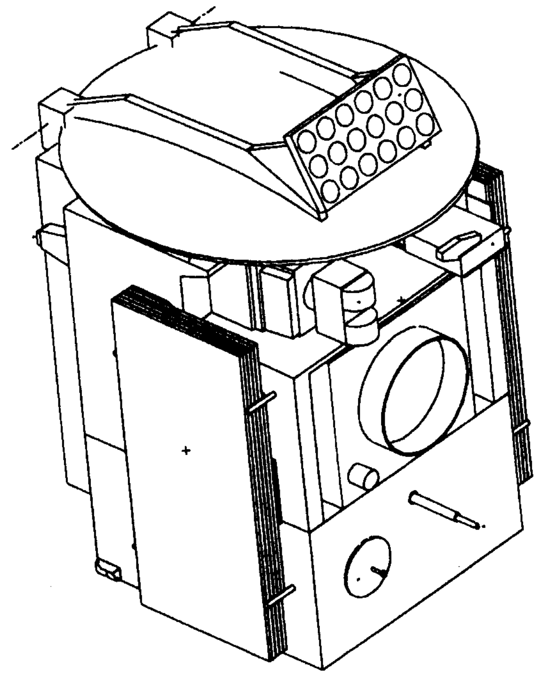
  - A single satellite in sun-synchronous orbit, 02:00 - 14:00 equator crossing times, at around 450 km altitude, carrying:
    - Backscatter Lidar (ATLID)
    - Cloud Profiling Radar (CPR)
    - Cloud Imager (ClIm)
    - Broadband Radiometer (BBR)

  - The ground segment, including three main functional elements
    - Command and Data Acquisition Element
    - Mission and Satellite Control Element
    - Processing and Archiving Element

2. BACKGROUND ON THE ERM

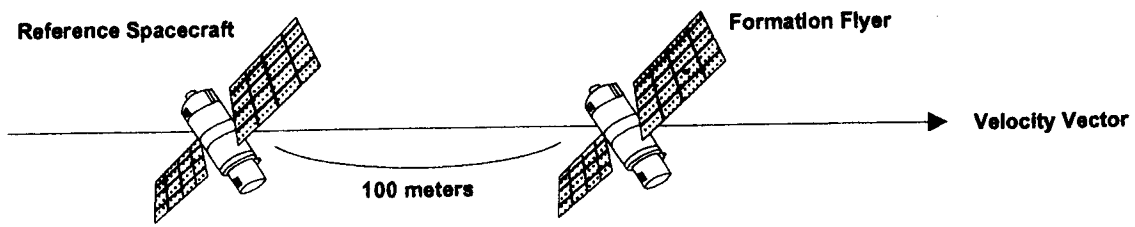


Deployed satellite configuration

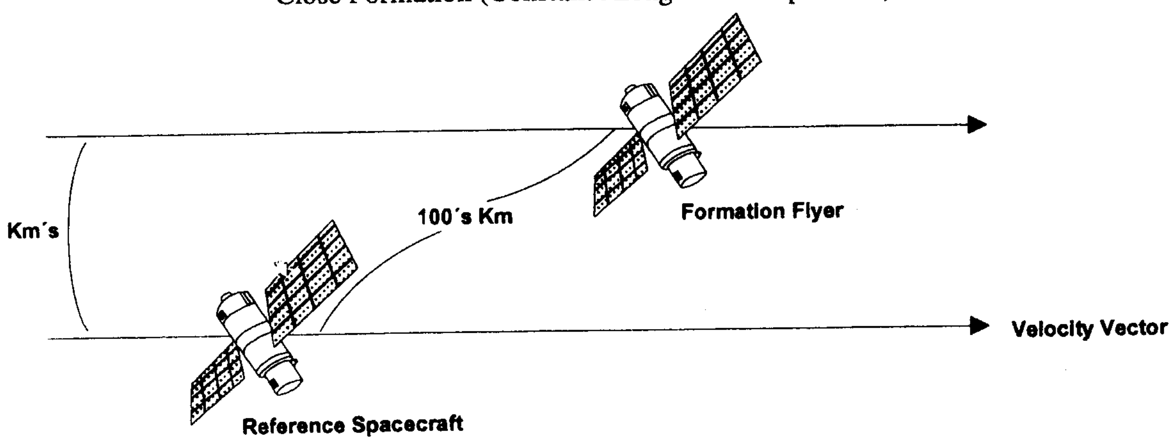


Stowed satellite configuration

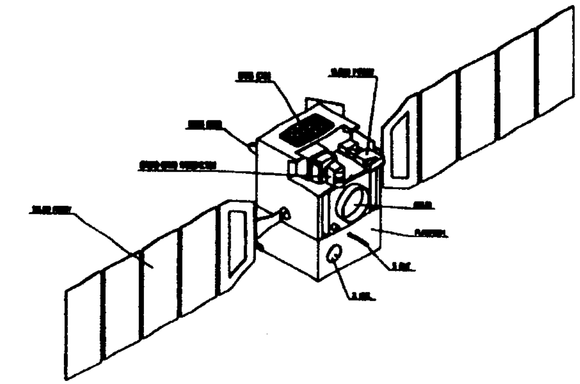
2. BACKGROUND ON THE ERM



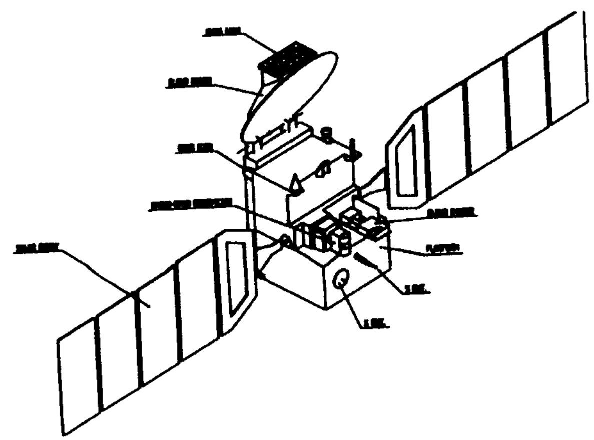
Close Formation (Constant Along-Track Separation)



Ideal Formation (Constant Across and Along-Track Separation)



The ERM without CPR

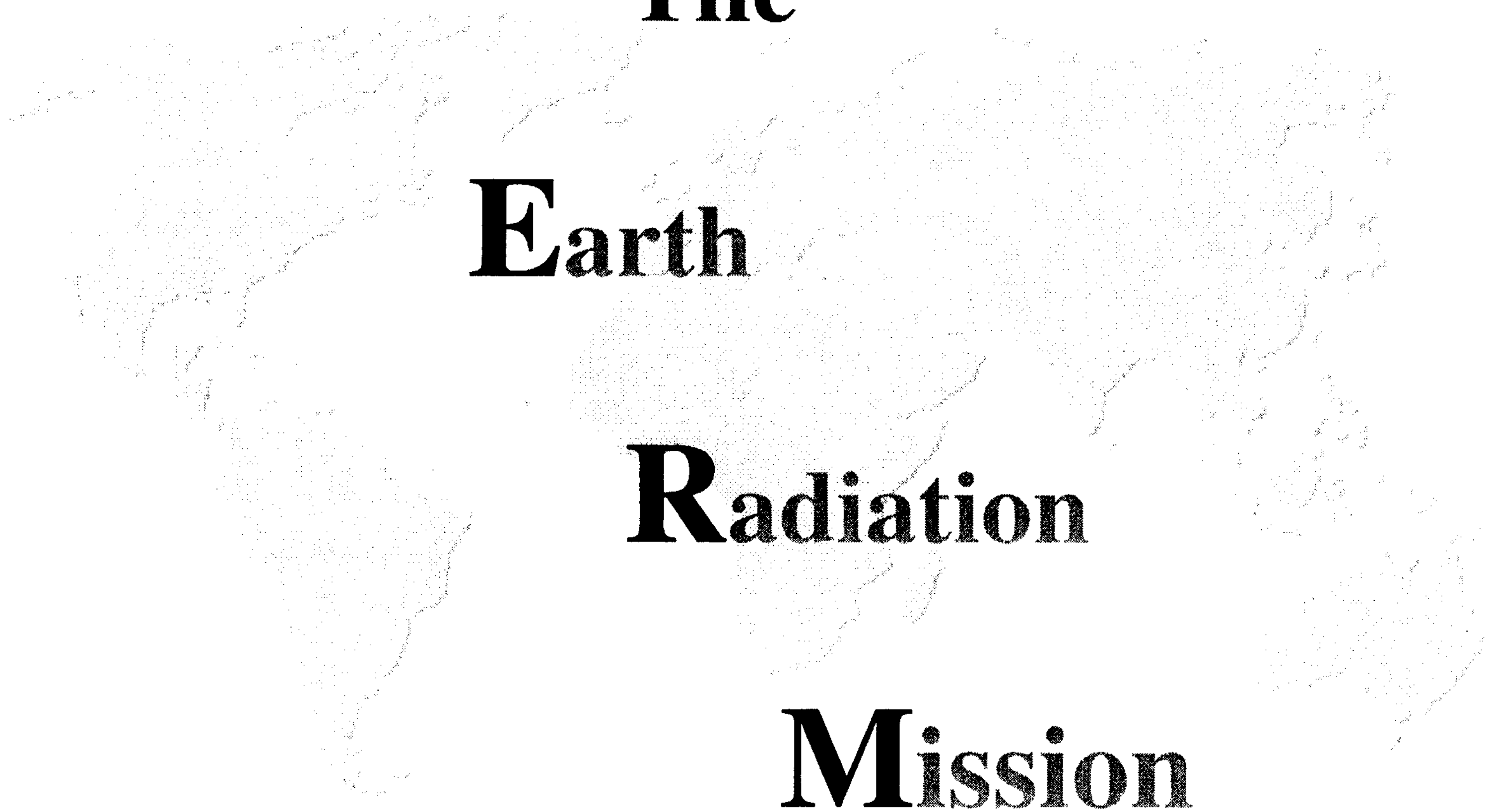


The ERM without ATLID

I. THE UNDERLYING SCIENCE

INTRODUCTION

P. INGMANN, ESA, EARTH SCIENCES DIVISION



The Earth Radiation Mission

The Earth Radiation Mission

Mission Objectives

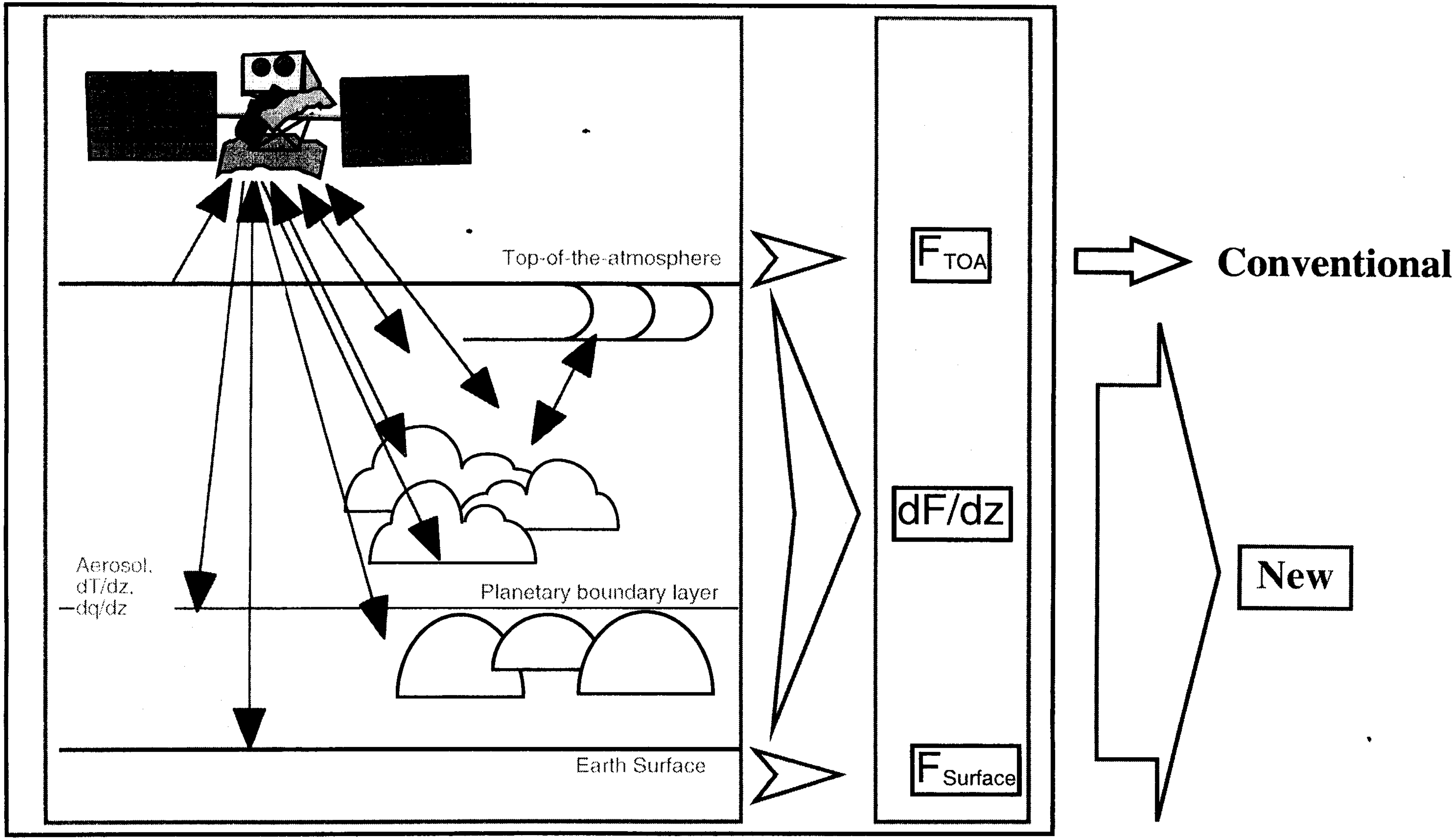
The **scientific objective** of the Earth Radiation Mission (ERM) is, for the first time, **to provide a multi-year set of cloud profiling and aerosol observations** essential to progress in understanding the transport of energy and water between the Earth's surface and the top of the atmosphere. The ERM components will:

- **measure vertical structure of cloud and aerosol fields** and their horizontal distribution over all climate zones;

- **measure the radiation budget components** at the top of the atmosphere simultaneously.

From these observations **the vertical structure and horizontal distribution of radiation budget components**, cloud water and cloud ice content, aerosol optical thickness, and other geophysical parameters will be derived, **using the ERM measurements in synergy with other simultaneous data.** Such observations would provide **additional constraints not provided by other means** helping in the **improvement of atmospheric numerical models**.

Scientific Objectives of the Earth Radiation Mission



The Earth Radiation Mission

- Products -

Solar Irradiance

Top-of-the-atmosphere shortwave radiation (reflected)
Top-of-the-atmosphere longwave radiation (emitted)

Cloud and aerosol characteristics

- **Vertical distribution (tops, bases)**
- **Fractional coverage**
- **Optical thickness**
- **Effective particle size**

and for clouds

- **Liquid/Ice water content**

Net surface flux

Vertical profiles of temperature and water vapour

Surface characteristics

F_{TOA}

Top of the Atmosphere

dF/dz

Surface

$F_{Surface}$

F ... Flux

vertical flux gradient

= not provided by this (satellite) mission but necessary for the scientific mission

Why do we need the Earth Radiation Mission?

Parameter	Current Uncertainty	Effect on downwelling infrared flux Wm^{-2} Sub-arctic Summer	Tropics
Specific humidity	20 %	11	15
Atmospheric temperature	2 K	5	8
Cloud base height	100 hPa	11	7
Fractional cloud cover	0.1	6	3
Doubling of CO_2 with 50% cloud cover, cloud base at 400 hPa		0.8	0.2
Doubling of CO_2 with no cloud cover, no feed-back		1.2	0.3

(after Chahine, 1992)

The Earth Radiation Mission

Radiative Flux Accuracies Required for the Mission

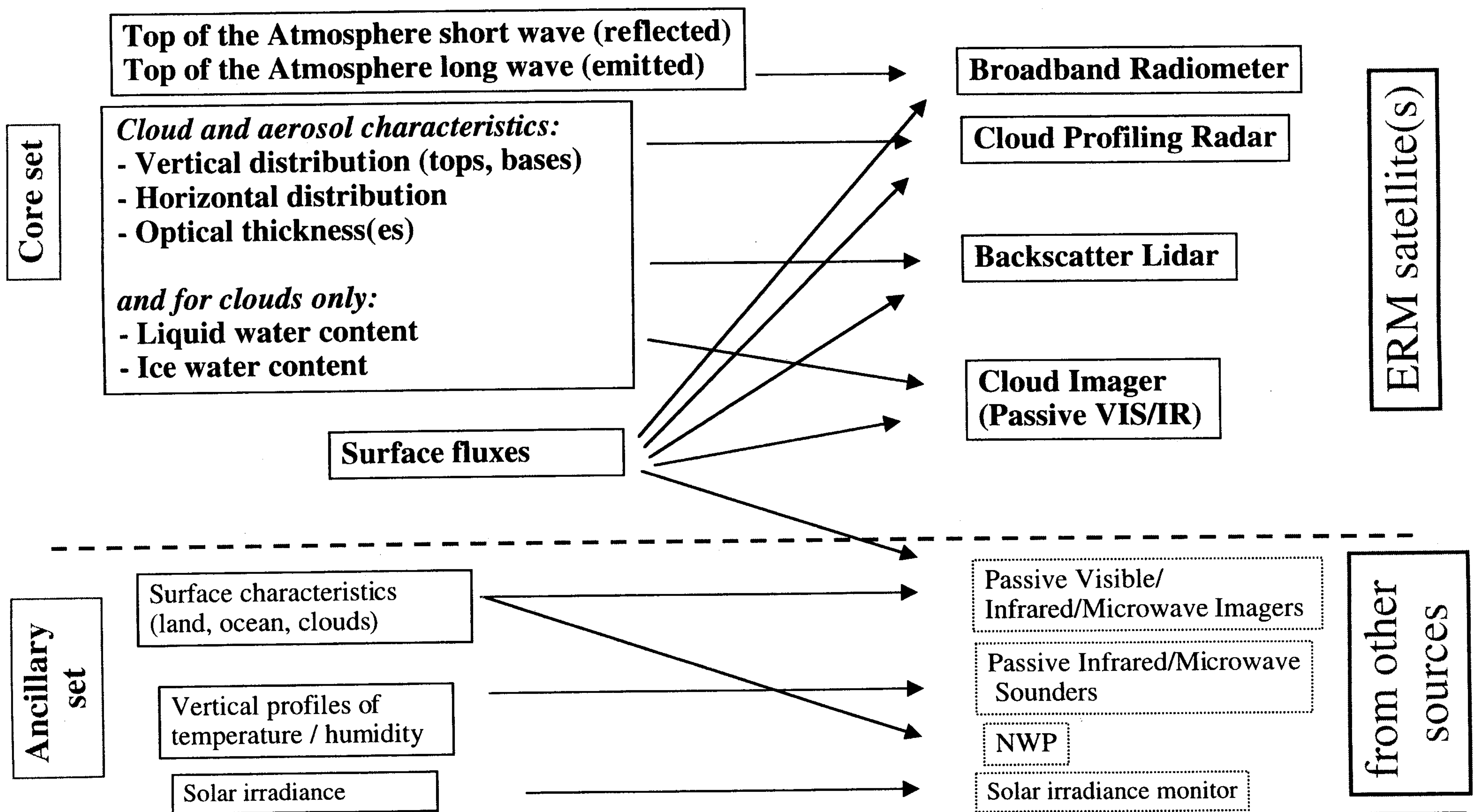
Measurement objective	Spatial coverage	Time domain	Desired Accuracy
Top of the atmosphere net radiative fluxes	50 x 50 km^2	instantaneous	< 10 Wm^{-2} (TBC)
Net radiative flux gradients/divergences within the atmosphere	50 x 50 km^2	instantaneous	< 10 $Wm^{-2}km^{-1}$ (TBC)
Net Earth surface fluxes	50 x 50 km^2	instantaneous	< 25 Wm^{-2} (TBC)

. cannot be measured directly

esa

Earth Sciences Division

The Elements of the Earth Radiation Mission



Scientific Studies

Various activities have either been carried out or are on-going:

- Effects of **multiple scattering** on the accuracy of a backscatter lidar
- Backscatter **lidar retrieval algorithms**
- **Critical requirements for a cloud profiling radar** (two separate presentations will follow)
- **Earth radiation database** (database available on the internet (http://www.dkrz.de)
- **Earth radiation budget mission scenario** study
- Study and measurements of **cloud characteristics** at Chilbolton
- **Synergy of passive and active instrumentation** in view of the Earth Radiation Mission (on-going, separate presentations will follow)
- **SW narrow-to-broadband conversion** for ERB (on-going)
- **Diurnal modeling** for ERB (on-going)

Scientific Studies (cont.)

- Analysis of **ERM synergy** by use of the **CLARA observations** (on-going, separate presentation will follow)
- **Quantification of ERM synergy** (on-going)
- **Impact of ERM observations on NWP** (on-going)
- **CLARE'98** (campaign - in preparation)

I. THE UNDERLYING SCIENCE

SYPAI: THE *S*Y*N*ERGETIC *P*ASSIVE AND *A*CTIVE *I*NSTRUMENT SIMULATOR

J.-P. BLANCHET, UNIVERSITY OF QUEBEC

SYPAI : The SYnergetic Passive and Active Instrument Simulator

Jean-Pierre Blanchet and Marc Larocque,
Earth Sciences Department, University of Quebec at Montreal (UQAM)
Peter Park and Ralph Girard, MPB Technology
Shiv Pal , Mark Cane and Dave Donovan, ISTS

Summary

Part 1 : Input data set

- Background
- RCModel description
- Scenario and input data set

Part 2 : SYPAI simulation tool

- Radiance calculation
- Instruments integration

Some Results

Working Context for the SYPAI Project

Introduction : the context
Objective of the project
Background

Global Climate Modeling
- Observation and General Circulation Models
- Present day climate simulations
- Climate change scenarios (2X CO_2)
- Radiation budget study : Li et al
- Cloud forcing and feedback : Cess et al

Regional Climate Modeling
- Rational & principles
- Dynamics (lab verification)
- Applications to regional scales : Clouds
- Multiple nesting strategy

Local Climate Modeling
- Rational & Principles
- Active diagnostics method
- Retrieval of cloud optical depth and transmittance

Application project
- MAM project
- NARCM Project
  1. Forest Fire project (Forestry Canada)
  2. Pollen transport project (CUM)
  3. Kuwait Oilfire project (NARCM)
  4. Atmosphere-Biosphere coupling project (Roulet et al, CRSNG)
  5. DMS emission and dispersion project (Levasseur, DOS)
  6. James Bay carbon emission project (Lucotte, Hydro-Québec)
  7. LITE mission project (Hoff, NASA/AES)

ESA : Satellite instrumental synergetic project
- Frame generation
- Available data
- Forward problem : instrument signal generation
- Backward problem : cloud data retrieval
- Study of instrument synergy.

Climate : A Process Oriented System

Prognostic equations of dynamics :

$$\frac{\partial \vec{V}}{\partial t} + \vec{V} \cdot \nabla \vec{V} + \omega \frac{\partial \vec{V}}{\partial p} - f \vec{k} \times \vec{V} + \nabla \Phi = \boxed{D_{Mom}}$$

$$\frac{\partial T}{\partial t} + \vec{V} \cdot \nabla T - \omega \left(\frac{\kappa T}{p} - \frac{\partial T}{\partial p} \right) = \boxed{\frac{Q_{Rad}}{C_p} + \frac{Q_{Cond}}{C_p} + D_{Heat}}$$

$$\frac{\partial q}{t} + \vec{V} \cdot \nabla q + \quad \frac{q}{t} = \boxed{E - C + D_{Moist}}$$

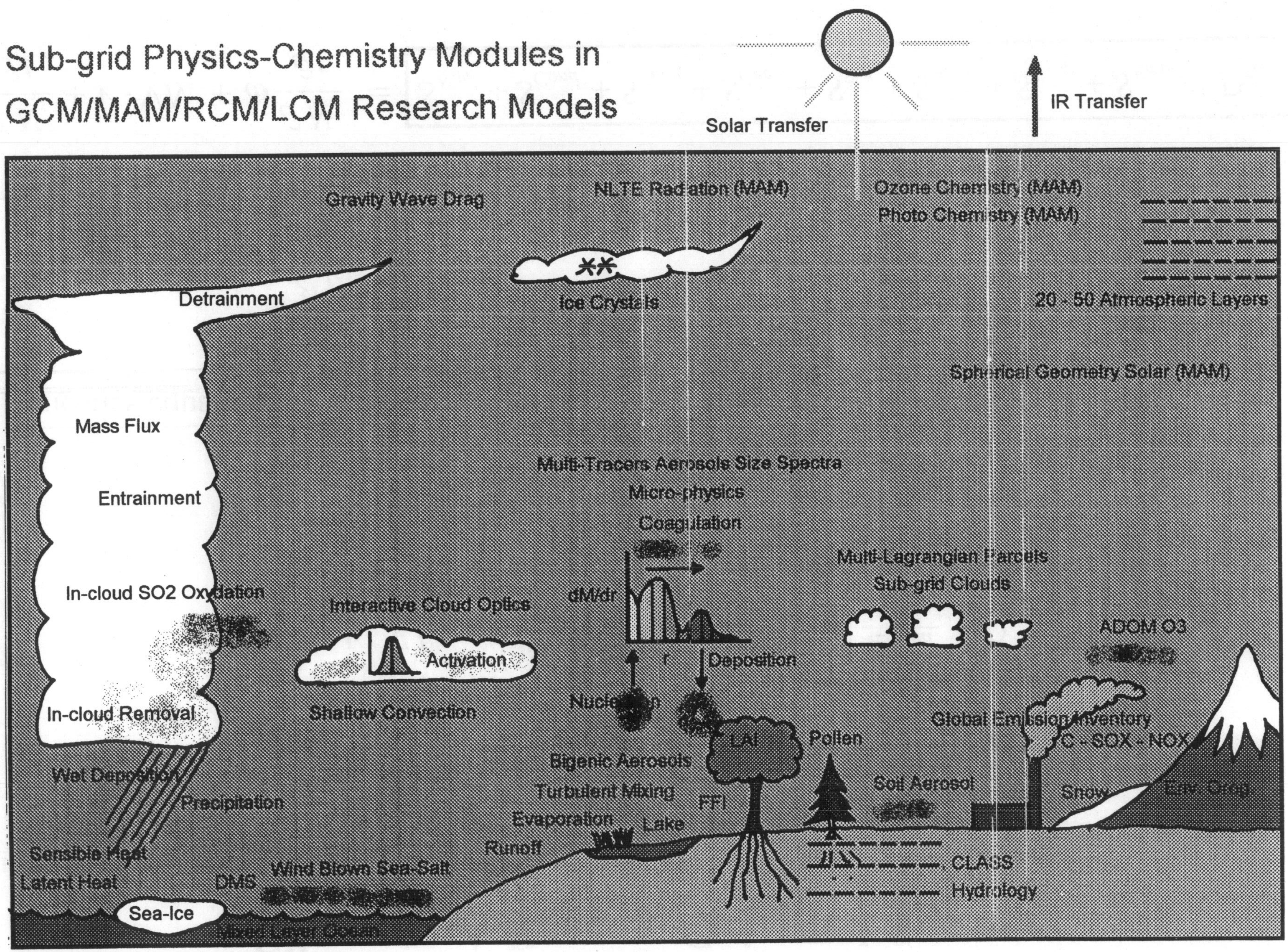
Diagnostics equations :

$$\frac{\partial \omega}{\partial p} + \nabla \cdot V = 0 \quad \text{and} \quad \frac{\partial \Phi}{\partial p} + \frac{R\,T}{p} = 0$$

Tracer constituents, Aerosol microphysics :

$$\frac{\partial N_i}{\partial t} + \vec{V} \cdot \nabla N_i + \omega \frac{\partial N_i}{\partial t} = \boxed{S_{Nucl} + S_{Cond} + S_{Coag} + S_{Chem} + S_{Sed} + S_{Activ} + S_{Evap} + S_{Emis} + D_{Tracer}}$$

Sub-grid Physics-Chemistry Modules in GCM/MAM/RCM/LCM Research Models



A Hierarchy of Processes

Level	Category	Process
1	Basic	Convection, advection, condensation, diffusion, gravity wave drag, surface drag, mixing, solar radiation (scattering, absorption...) thermal radiation, convection, freezing, evaporation and similar
2	Mixed	Clouds by types (orographic clouds, large-scale cyclones, jet streams, deep convection systems, mesoscale systems, ITCZ and tropical storms, ocean stratocumulus, polar clouds, cirrus, Cb detrainment, continental fair weather Cu, etc.), all characterized by droplet size distribution, ice crystals shape and distribution, water content profiles, top/base temperature and heights... (Similar mixed process subdivision applies to vegetation, sea-ice, continental snow, soil hydrology... could be defined but they are not of direct concerns for the ERM.)
3	Integrated	Heating rates, TOA balance, surface energy budget

Background

- ERM : from a Radiation budget to a process oriented mission

  The traditional Earth Radiation Budget Experiment is essential for the specification of climate and its trend. However, it is inadequate for the validation of climate models and prediction.

- Processes and understanding our climate system

  The fundamental set of prognostic equations for the climate system has a finite number of basic physical processes that determine the behavior of the system.

- Process signature in cloud properties

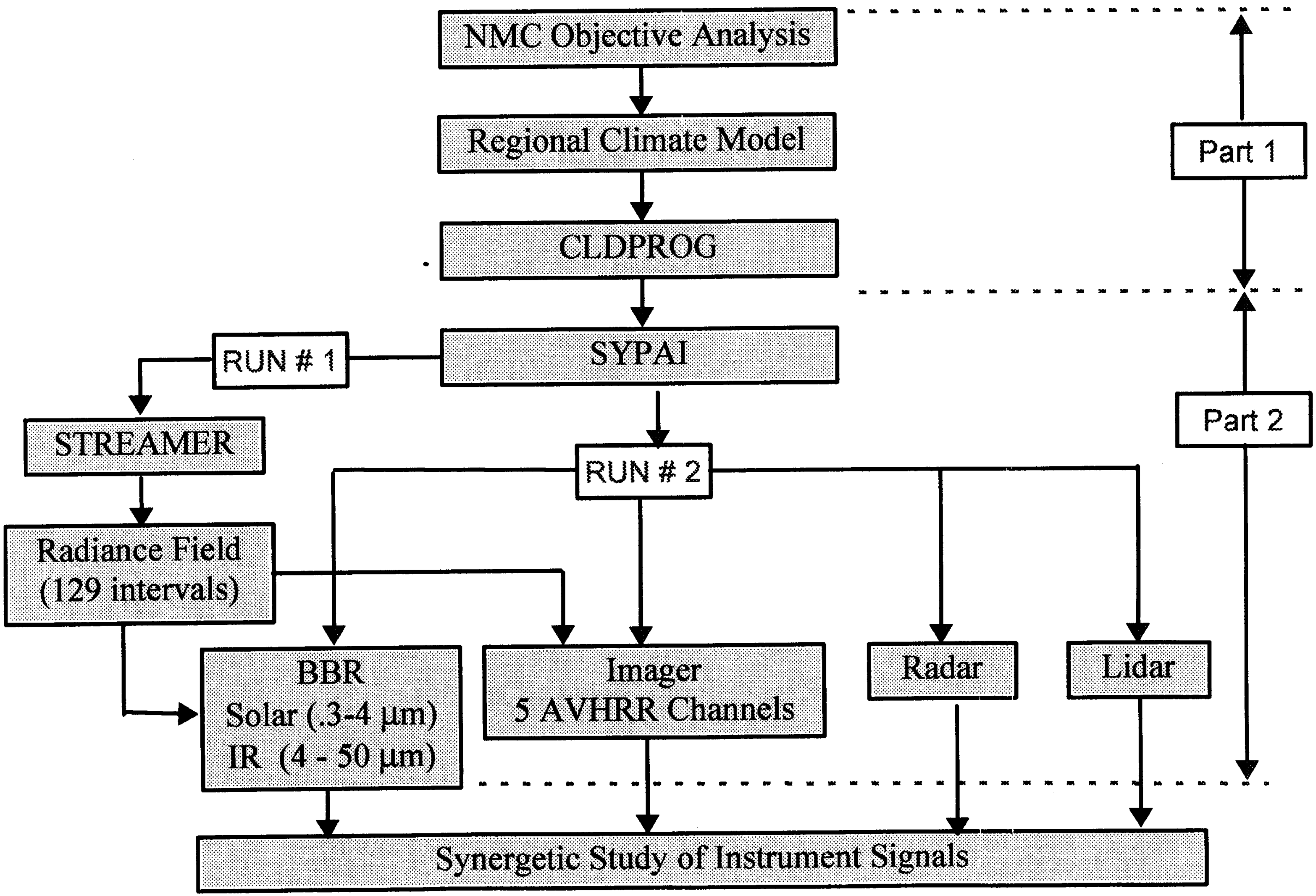
  The cloud structure is strongly affected by most of these fundamental processes and, therefore, high quality monitoring of many small sample offers extremely valuable data for improvement of climate study and prediction.

- Confinement of climate models to validate fundamental physical processes.

  By running climate model in forecast mode, they can be directly compared to ERM measurements for assessment of cloud related processes. The ERM data set can reused often for testing model improvements.

- Clouds are the most significant modulator of the Earth's energy budget. The proper account of cloud in observation and model can only be achieved by including a proper treatment of aerosol microphysics.

Generation of the Input Data Set



Summary

- GCM/RCG climate models are used to generate 3D grids of field variables that are consistent with observed conditions.
- Simulations are compared to results from LITE mission.
- Usual atmospheric data are provided as input to detail radiative transfer calculation and for diagnostics. They are :

  ⇒ **Input to RT code** : grid profiles of temperature, height, water vapour, ozone, aerosols, clouds cover, liquid water content, optical depth, equivalent radius, water phase and surface conditions.

  ⇒ **Output for diagnostics** : Solar/IR heating rates profiles, solar/IR flux profiles, TOA, surface energy balance and cloud forcing.

- RT code (DisORT) computes transmittance satellite-targets and radiance sun-target-satellite for selected band range for each computational points in plane parallel geometry.
- Radiance is integrated within the view angle or scan range.
- Instrument response functions are applied to produce synthetic measurements.
- Retrievals of cloud properties and radiation fluxes are inferred from standard algorithm.
- Comparisons are made with the RCM generated data.

« Instrument synergy study begins ».

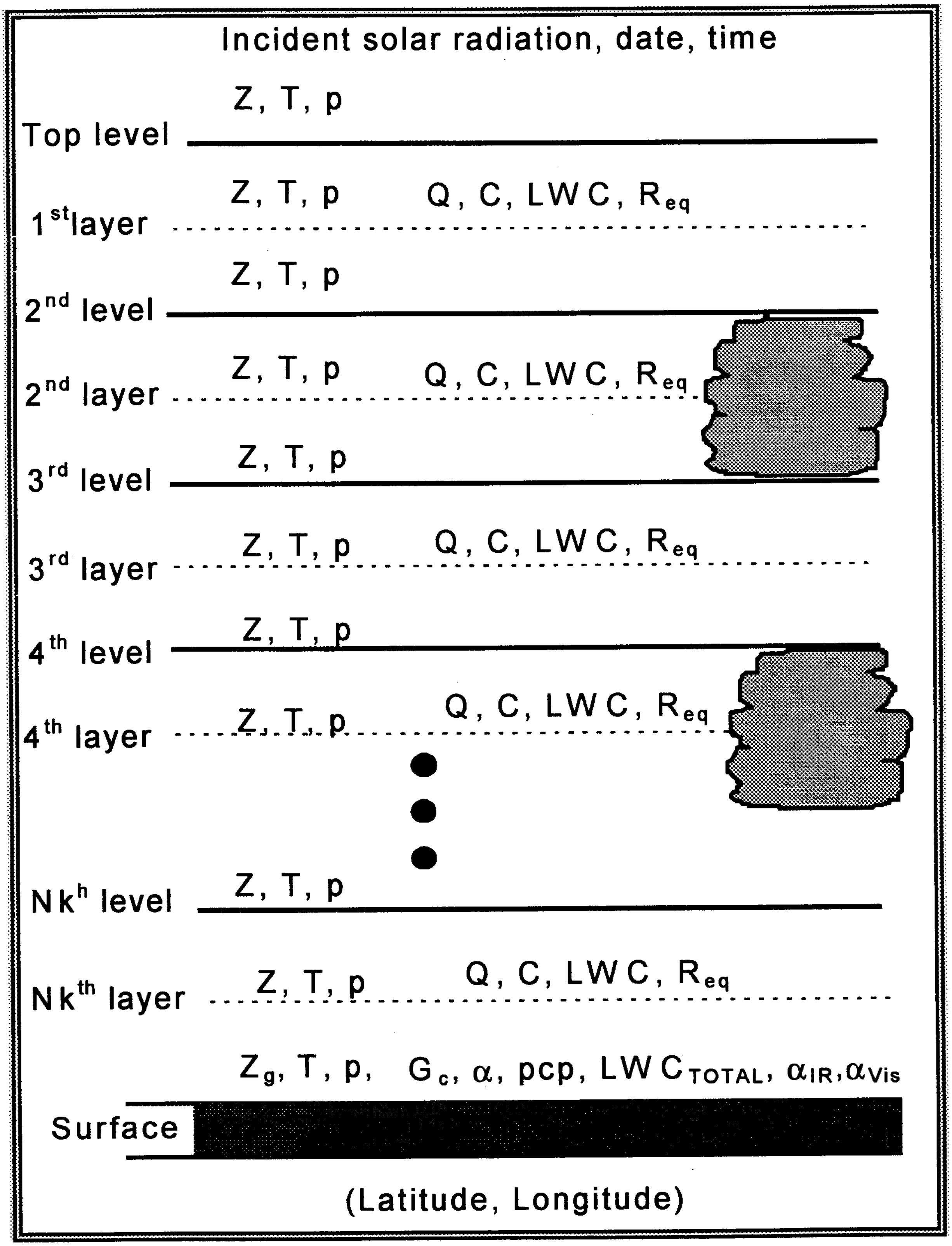
PART 1

DATASET GENERATION USING RCM AND PRE-ANALYSIS DIAGNOSTICS

Definition of the Input Data Set

```
TYPE Grid_Point                                    ! [Units]
     SEQUENCE
     REAL Latitude, Longitude                      ! [deg]
     REAL Height_Lev(Nk)                           ! [m]
     REAL Height_Lay(Nk)                           ! [m]
     REAL Temperature_Lev(Nk)                      ! [K]
     REAL Temperature_Lay(Nk)                      ! [K]
     REAL Pressure_Lev(Nk)                         ! [hPa]
     REAL Pressure_Lay(Nk)                         ! [hPa]
     REAL Relative_Humidity(Nk)                    ! [fraction]
     REAL Cloud_Cover(Nk)                          ! [fraction]
     REAL Liquide_Water_Content(Nk)                ! [g/m3]
     REAL Equivalent_Radius(Nk)                    ! [um]
     INTEGER Phase(nk)                             ! [0,1]
     REAL Concentration(nk)                        ! [number/cm^3]
     REAL Surface_Type                             ! [-1,0,1]
     REAL Surface_Pressure                         ! [hPa]
     REAL Surface_Temperature                      ! [K]
     REAL Surface_Albedo                           ! [fraction]
     REAL Surface_Height                           ! [m]
     REAL Surface_Precipitation                    ! [mm/s]
     REAL Column_Liq_Water_Content                 ! [g/m3]
     REAL Surface_AlbedoI                          ! [fraction]
     REAL Surface_AlbedoV                          ! [fraction]
END TYPE Grid_Point
```

Structure of the Atmospheric Data Set



PART 2

SYPAI STRUCTURE AND DESCRIPTION

Cloud Microphysics

$$C = \frac{(H - H_o)}{(1 - H_o)}.$$

$$\text{Phase} = \begin{cases} 0 & \text{if } T > T_{ice} + \sigma_T P \\ 1 & \text{if } T \leq T_{ice} + \sigma_T P \end{cases}$$

$$X_{ave} = 0.698 + 0.366\,L + 0.122\,L^2 + 0.0136\,L^3$$

$$X_{max} = 4.45 + 3.42\,L + 1.06\,L^2 + 0.115\,L^3$$

$$L = \log_{10}(LWC).$$

$$Re_{ice} = 5640\,(X_{ave} / 100)^{0.786} + 13$$

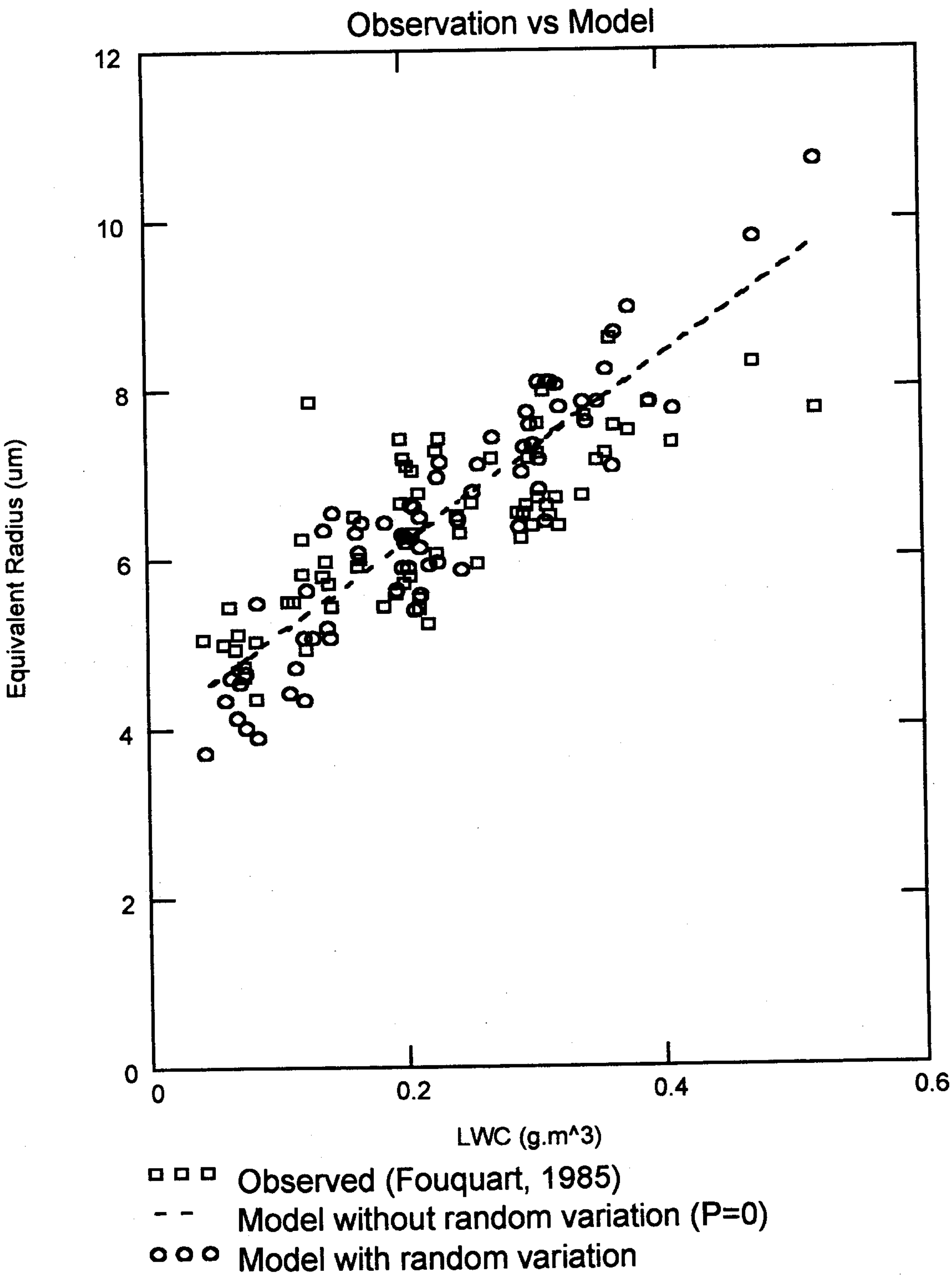
$$\rho_{ice} = 650\,X_{ave}^{-0.915}$$

$$C_{ice} = 3\text{x}10^{12}\,(LWC / 4\pi\,\rho_{ice}\,Re_{ice}^3)$$

$$Re_w = 11\,LWC + 4 + P$$

$$C_w = 3\text{x}10^{12}\,(LWC / 4\pi\,\rho_w\,Re_w^3)$$

Comparison of Model Equivalent Radius vs Observations



User Interface : Input Data File

```
<<<<<<<<<<<<<<<<<<<<<<<<< INPUT DATA FOR SYPAI >>>>>>>>>>>>>>>>>>>>>>>>>
Definition of the scene (binary file)
!------------------------------------------------------------------------
      MAP07km.dau
-------------------------------------------------------------------------
Input data set file name

                                    ***************
                                    *    RADAR    *
                                    ***************
!------------------------------------------------------------------------
     1          1
-------------------------------------------------------------------------
  itest  |  itest_traj = ioption_traj


-------------------------------------------------------------------------
  500.d3    1       1           1
-------------------------------------------------------------------------
   Hsat    iobs   isave   ioption_data

-------------------------------------------------------------------------
       1000.
-------------------------------------------------------------------------
  radar_hsampling

                                    ***************
                                    *    LIDAR    *
                                    ***************
!------------------------------------------------------------------------
      lidar.dat
-------------------------------------------------------------------------
  Lidar data file

!------------------------------------------------------------------------
     aerosol.dat
-------------------------------------------------------------------------
 Fix aerosol data file

!------------------------------------------------------------------------
     watercld.dat
-------------------------------------------------------------------------
 Water cloud data file

!------------------------------------------------------------------------
   y      T
-------------------------------------------------------------------------
  str   noise   :  str=y(es) ---> noise=true
                   str=n(o)  ---> noise=false
!------------------------------------------------------------------------
   23          2
-------------------------------------------------------------------------
  idum    ioption_traj
!------------------------------------------------------------------------
  13      14       15
-------------------------------------------------------------------------
ifile1   ifile2   ifile3
```

User Interface : Input Data File . . .

```
                              ***************
                              *  IMAGER/BBR  *
                              ***************
!----------------------------------------------------------------------
 1 2 0 0 0   1 2 6 10 9 0 0 0 0 0 0   T        T        31 35     F
-----------------------------------------------------------------------
kins(i)=1,5 |       ip(i)=1,11      | cont | display  |  Is Js  | load
stores
setting from
disc to disc

                              ***************
                              *     RTC     *
                              ***************
!----------------------------------------------------------------------
  F
-----------------------------------------------------------------------
irtc: TRUE    DO FULL CALCULATION INTO STREAMER
      FALSE   USE RADIANCE ARCHIVED TABLE

<<<<<<<<<<<<<<<<<<<<<< INFORMATION ON PARAMETERS >>>>>>>>>>>>>>>>>>>>>>
Input file data names:
======================


Files Naming conventions:
=========================



Input parameters :
==================
   ioption:
   itraj  :



  itest=0   No test. IJ_orbit defined in SYPAI
  itest=1   IJ_orbit generated here using  orbit.inp

  ioption_traj=1    One uses the longitudes and latitudes
                    corresponding to IJ_orbit()
                    Caveat:  Does not match necessarily
                    radar_hsampling and therefore noise can be
                    erroneous
  ioption_traj=2    Trajectory goes along orbit points
                    xlatin,xlongin to xlatfin, xlongfin
                    intermediate points are generated with a spacing
                    equal to radar_hsampling
                    This should the normal way of operation when
                    active instruments are properly aligned.

    Cloud radar retrieval is controlled by ioption_data
    ioption_data=1          One uses variable already available
                            in commons assigned by radar_frameobs
    ioption_data=2          Data is read from file.
                            radar_retrieval can be called independently
                            of other programs.
```

User Interface : Entry to Main Pogram

```
C<<<<<<<<<<<<<<<<<<<<<<<<<<<<<< Main Program >>>>>>>>>>>>>>>>>>>>>>>>>>>>>>
      PROGRAM SYPAI

CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C                                                                        C
C  This program is the "SYnergetic Passive and Active Instrument"       C
C  (SYPAI) main simulator.                                               C
C                                                                        C
C  Data Structure: Relevant data for radiative transfer calculations     C
C  --------------  are used as derived type of structured object         C
C                  variables at each grid points (or pixels) of the      C
C                  frame. A frame is composed of Ni by Nj by Nk compu-   C
C                  tational points spread over Ni by Nj pixels.          C
C  The horizontal plane is a polar stereographic projection with Ni      C
C  latitudes and Nj longitudes. The origin is located at the lower-      C
C  left corner of the grid. Points are ordered sequentially from         C
C  the origin Eastward along longitude first and then Northward along    C
C  latitudes, e.g., the coordinate (i,j) is the record number IJ given   C
C  by                                                                    C
C                        IJ = (i-1)*Nj + j                               C
C                                                                        C
C  The vertical structure is composed of Nk material layers (Lay)        C
C  bounded by interface levels (Lev) as follows                          C
C                                                                        C
C    ___________________________   Lev 1    (Z,P,T)                      C
C              (,,,,,)                                                   C
C    ..........(.....)..........   Lay 1    (Z,P,T,H,C,L,R)              C
C              (,Cld,)                                                   C
C    __________(_____)__________   Lev 2    (Z,P,T)                      C
C                                                                        C
C    ...........................   Lay 2    (Z,P,T,H,C,L,R)              C
C                                                                        C
C    ___________________________   Lev 3    (Z,P,T)                      C
C          (,,,,,),                                                      C
C    ......(.....)..............   Lay 3    (Z,P,T,H,C,L,R)              C
C          (,Cld,)                                                       C
C    ______(_____)______________     *                                   C
C                                    *                                   C
C    ...........................     *                                   C
C                   .                *                                   C
C                                  Lev Nk   (Z,P,T)                      C
C    ___________________________                                         C
C                                                                        C
C    ...........................   Lay Nk   (Z,P,T,H,C,L,R)              C
C                                                                        C
C                                                                        C
C    ///////////////////////////   Surface  (Z,P,T,type,albedo,pcp,TLWC)C
C                                               albedoV,albedoI          C
C                                                                        C
C  the vertical index starts at the top and increases downward. All     C
C  levels/layers are assumed to be located at the same height Z (m).    C
C  Pressure P (Pa) is variable together with temperature T (K).         C
C  Layers are characterized by humidity (fraction), fractional          C
C  cloud amount (C), cloud liquid water content L (g/m3) and cloud      C
C  particles effective radius R (um). The surface is further charac-    C
C  terized by type (-1 soil, 0 water, 1 ice), albedo, albedoI,          C
C  albedoV, precipitation (mm/s) and integrated vertical water          C
C  content TLWC (g/m3).                                                  C
C                                                                        C
C  Authors: Jean-Pierre Blanchet and Marc Larocque                      C
C                                                                        C
C  Version: BETA   Date: June 9, 1997                                   C
C                                                                        C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
```

Main Program : SYPAI.f

```
      PROGRAM SYPAI
C........Define FRM Instrument Characteristics
C     CALL Instruments

C.....Location of the pixel and Radiance (STREAMER-DISORT)
      IJ = NI*NJ + 1
      CALL Get_Pixel2 (Place,Pixel,IJo,IJ,ID)
      WRITE(*,*) Place
      IF (FullRTC) THEN
         WRITE (*,601)
         DO 110 ki = 1, 1          ! ni
            DO 100 kj = 1, 1       ! nj
               IJ = Indx (Ki,Kj,Ni,Nj)
               CALL Get_Pixel2(Place,Pixel,IJo,IJ,ID)
               CALL Radiance (BBR_signal, Place,Pixel,ki,kj,ij)
C              CALL Sample (Pixel,IJ,ki,kj)
  100       CONTINUE
  110    CONTINUE
      ELSE  ! Do only reading of pre-calculated radiances
         WRITE(*,*) ' RTC IN TABLE FORMAT '
         CALL rad_data
      END IF

C........Run Active Instruments
C........Radar
      CALL RADAR (itest,itest_traj)

C........LIDAR
      CALL LIDARmain (frame_handle,pixel_file,ifile1,ifile2,ifile3,
     2         instrument_datafile,aerosol_datafile,cloud_datafile,
     3         xlongin,xlatin,xlongfin,xlatfin,noise,itest,ioption_traj)

C........Run Passive Instruments
C........BBR/IMAGER
      CALL BBR_IMAGER !cn282

C........Non-Synergetic Retrievals
C     CALL Retriev (LIDAR_signal,RADAR_signal,BBR_signal,IMAGER_signal)

C........Data fusion & Synergetic Retrieval
C     CALL Synergy (LIDAR_signal,RADAR_signal,BBR_signal,IMAGER_signal)

      CLOSE (ID)
      STOP 'OK'
```

Output of RCM

Output files	Variable name
ALBS.DAT	Surface albedo
ALSI.DAT	Infra-red albedo
ALSV.DAT	Visible albedo
CLDCOV.DAT	Cloud cover
GCOVER.DAT	Ground cover
GHUM.DAT	Humidity
GTEMP.DAT	Ground temperature
HGHT.DAT	Height level
LWCD.DAT	Liquid water content
LYRHGHT.DAT	Height layer
LYRPRES.DAT	Pressure layer
LYRTEMP.DAT	Temperature layer
PRECIP.DAT	Precipitation
PRES.DAT	Pressure Level
RADIUS.DAT	Equivalent radius
SURFACP.DAT	Surface pressure
TEMP.DAT	Temperature level
TLWC.DAT	Total liquid water content
TOPOGFY.DAT	Height of topography

Exemple of the MAKEFILE structure.

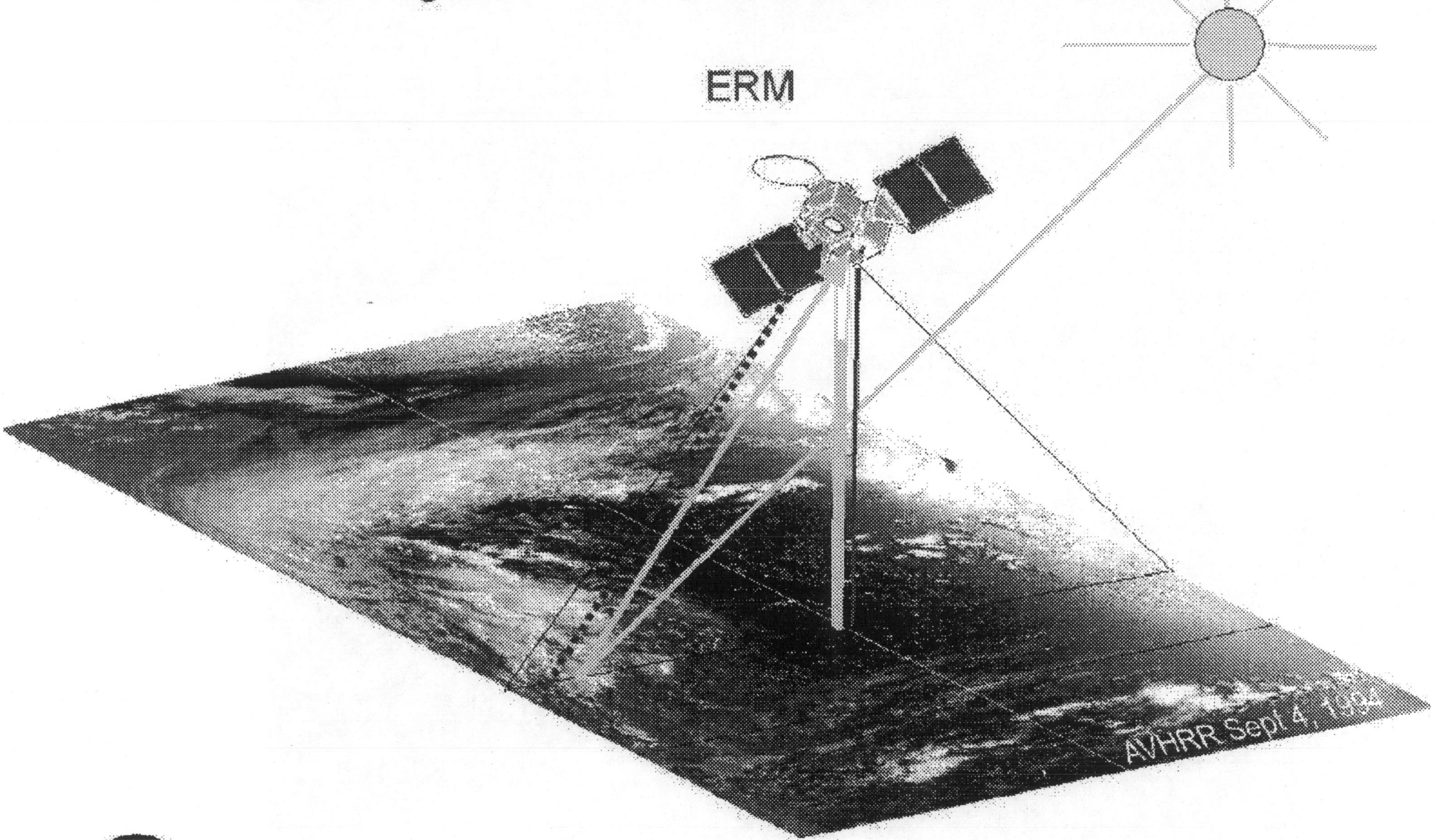
```
#
# Makefile for building Sypai with option for debugging.
#             *** IBM VERSION, AIX 3.2.5 ***
#
#  Modified by Marc Larocque  June 18 1997
#  Work for the IBM under AIX 4.0

.SUFFIXES:
.SUFFIXES:.f .o

SHELL = /bin/sh
CPP = /lib/cpp
FC = f90
LINKER = f90
MY_PATH = /obelix1/larocque/ESA2

DIR_SYPAI  = $(MY_PATH)
DIR_RTC    = $(MY_PATH)/RTC
DIR_RADAR = $(MY_PATH)/RADAR01
DIR_LIDAR  = $(MY_PATH)/LIDAR

SYPAILIB   =  sypailib.a
RTCLIB     =  rtclib.a
RADARLIB  =  radarlib.a
LIDARLIB   =  lidarlib.a

.PRECIOUS: $(SYPAILIB)
.PRECIOUS: $(RTCLIB)
.PRECIOUS: $(RADARLIB)
.PRECIOUS: $(LIDARLIB)

PROGRAM = sypai_b23
OSYPAI = sypai_b23.o ran1.o
FSYPAI = sypai_b23.f
#
FFLAGS = -c -g -static  # -qfixed
$(PROGRAM) : $(OSYPAI)
   $(LINKER) $(OSYPAI) $(DIR_RTC)/$(RTCLIB)
$(DIR_RADAR)/
   $(RADARLIB) $(DIR_LIDAR)/$(LIDARLIB) -o
$(PROGRAM)

sypai_b23.o : $(<F)
        $(FC) $(<F) $(FFLAGS)
RTC1:
        cd $(DIR_RTC); make rtc; make genlib
RADAR1:
        cd $(DIR_RADAR); make ; make genlib
LIDAR1:
        cd $(DIR_LIDAR); make ; make genlib
clean:
        rm -f *.o sypai_b23
```

RESULTS

CASE STUDY SEPTEMBER 4, 1994 SYNOPTIC STORM

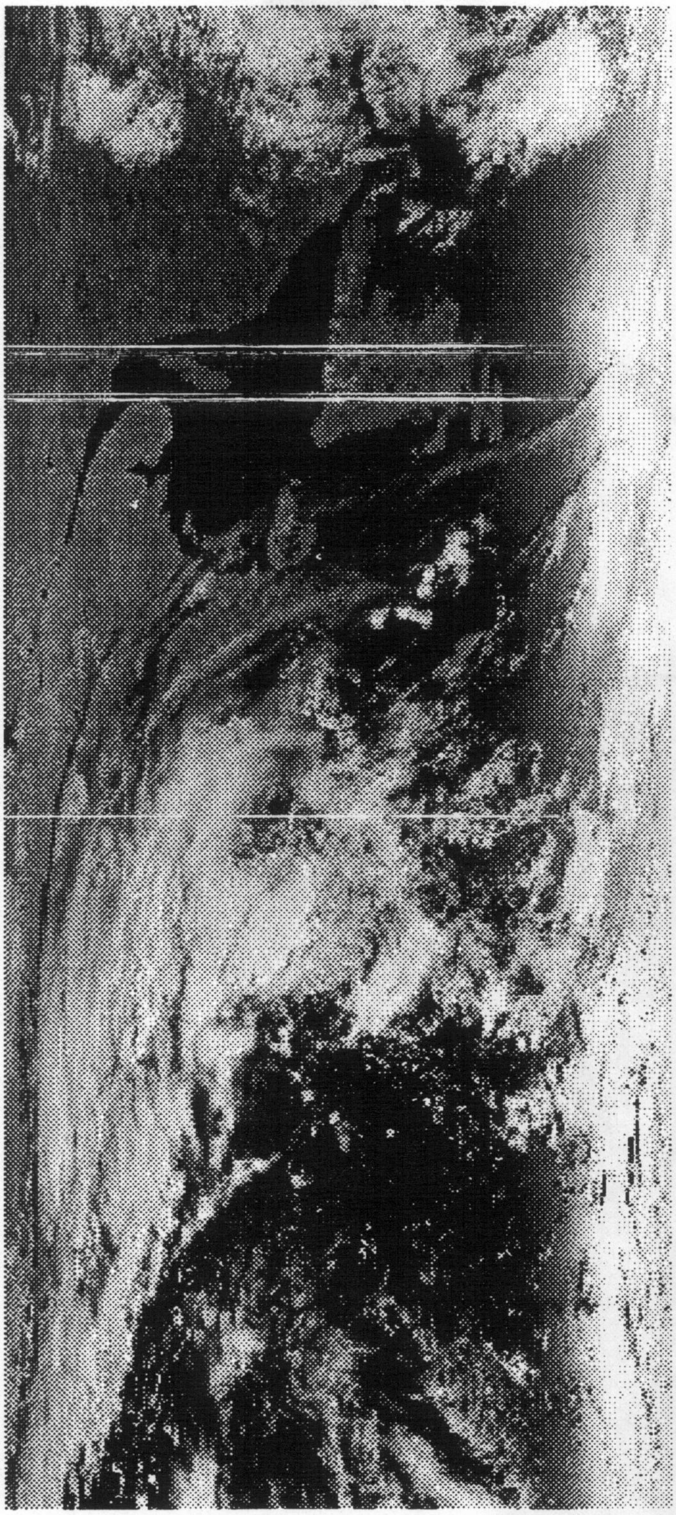
SYPAI: **SY**nergetic **P**assive and **A**ctive **I**nstrument Simulator

ERM

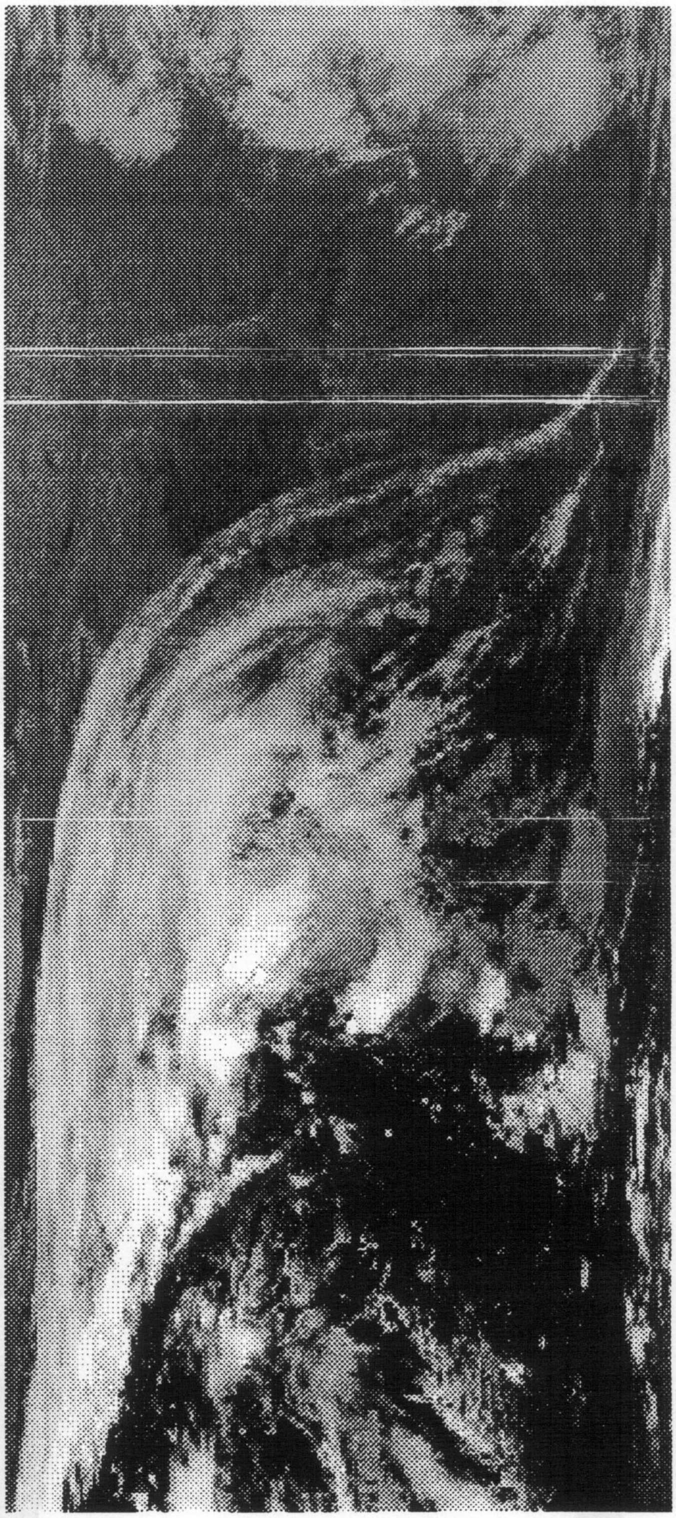


AVHRR Imager Sept 4, 1994

Channel 2

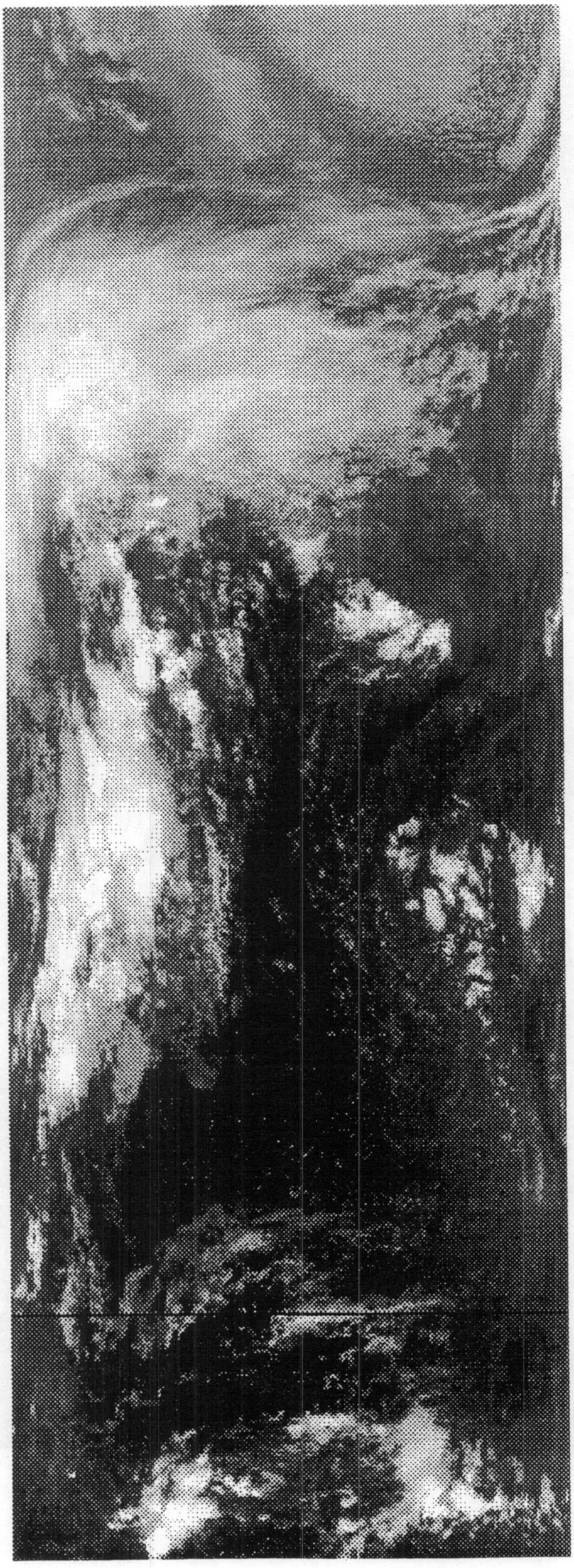


Channel 4

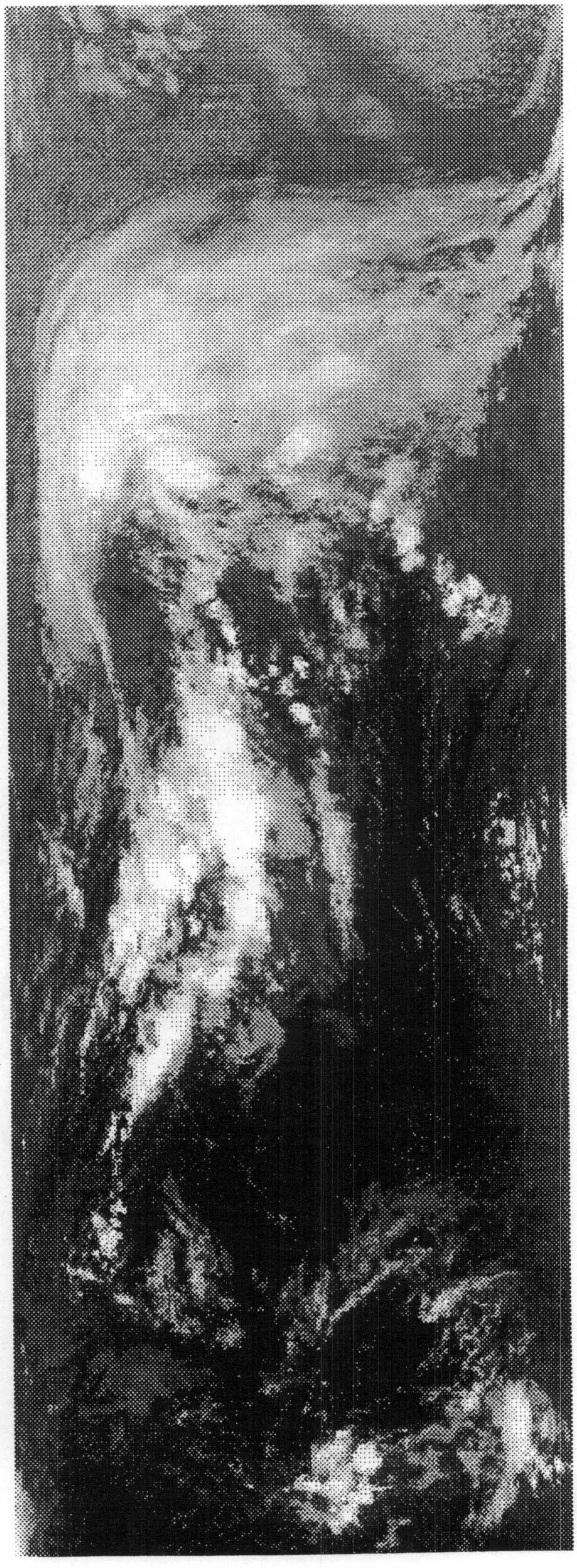


AVHRR Imager Sept 5, 1994

Channel 4

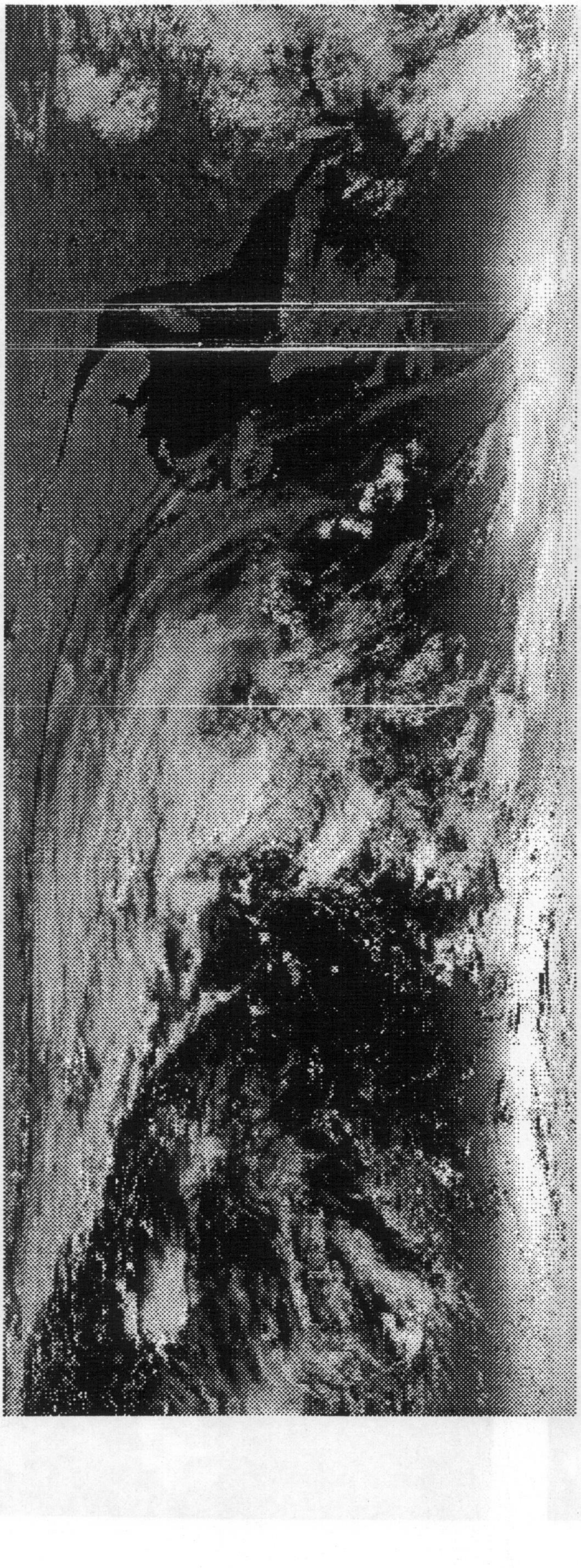


Channel 4

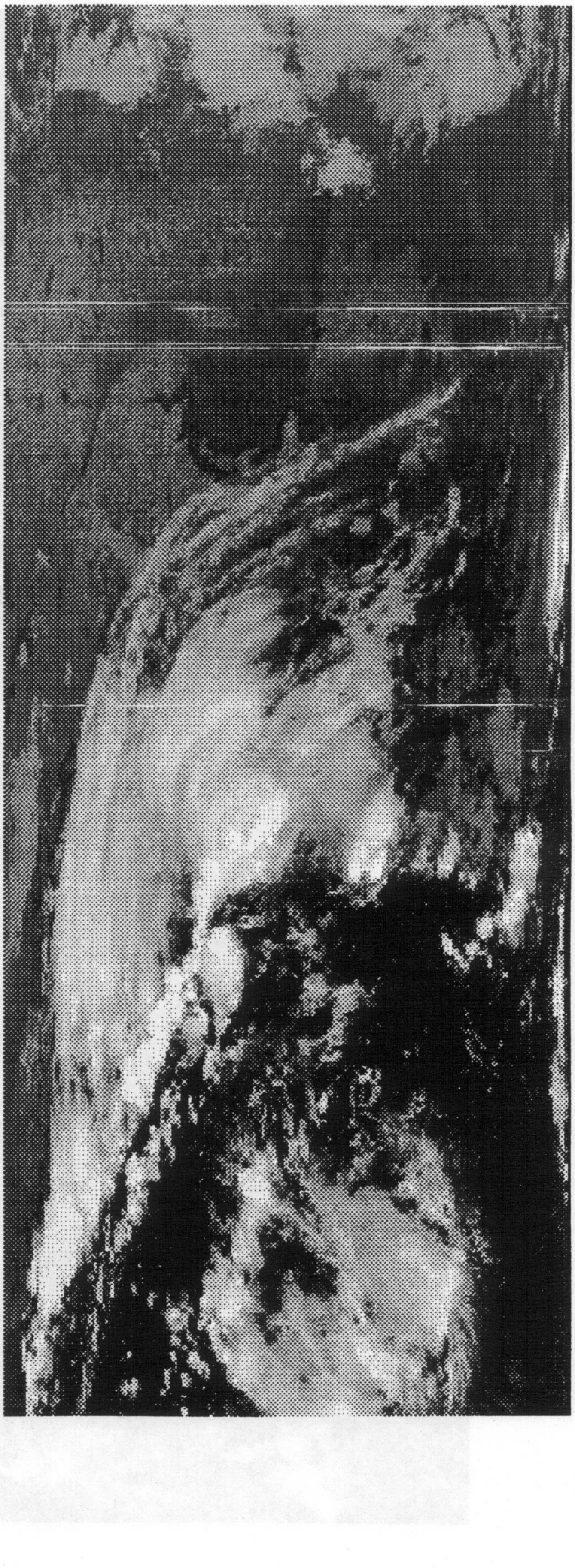


AVHRR Imager Sept 4, 1994

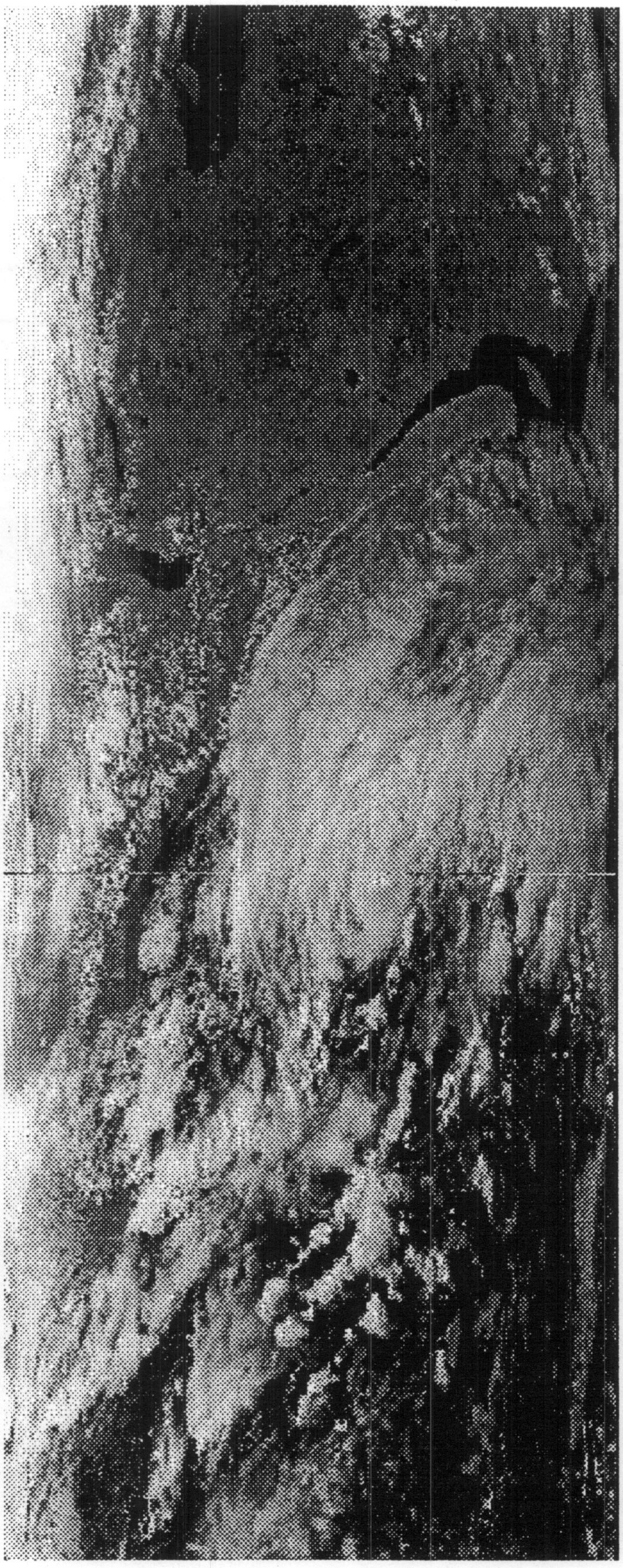
Channel 2



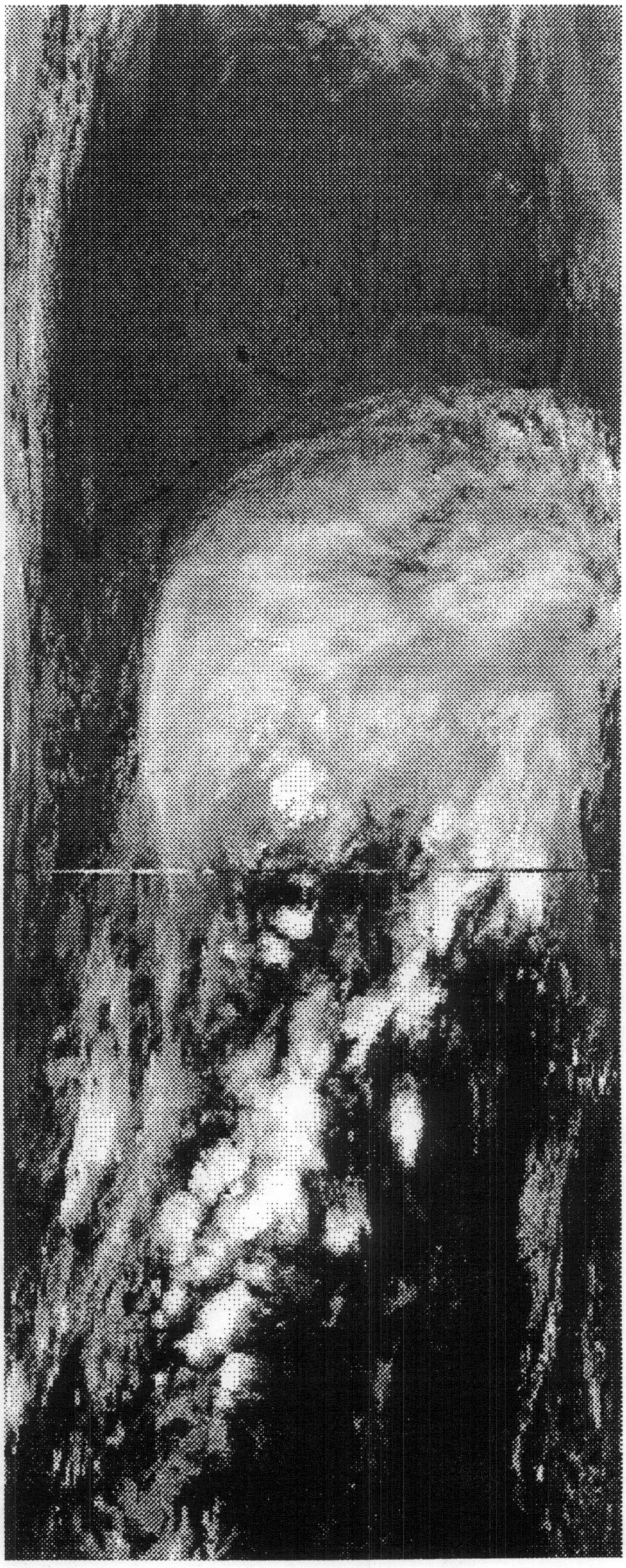
Channel 4



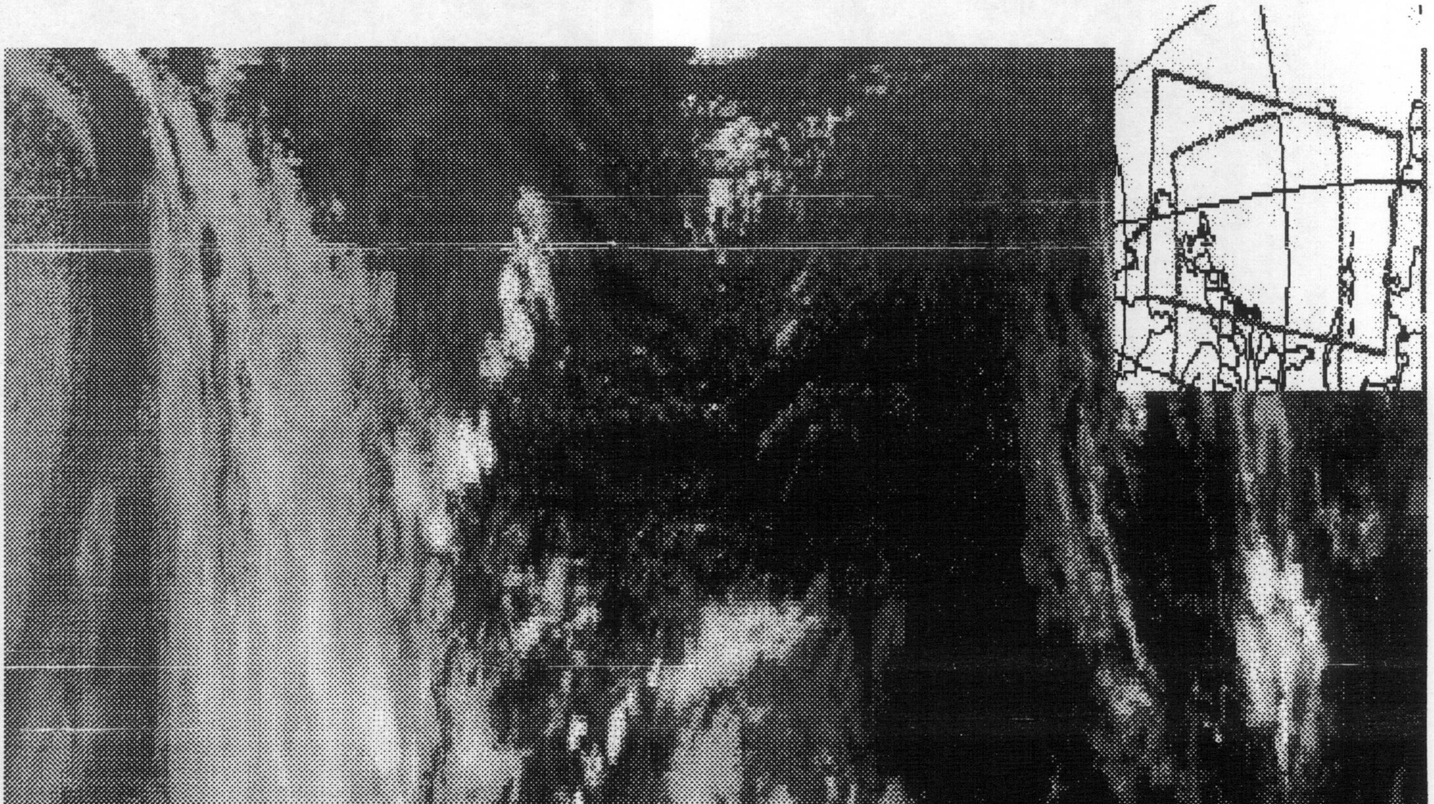
AVHRR Imager Sept 4, 1994



Channel 2

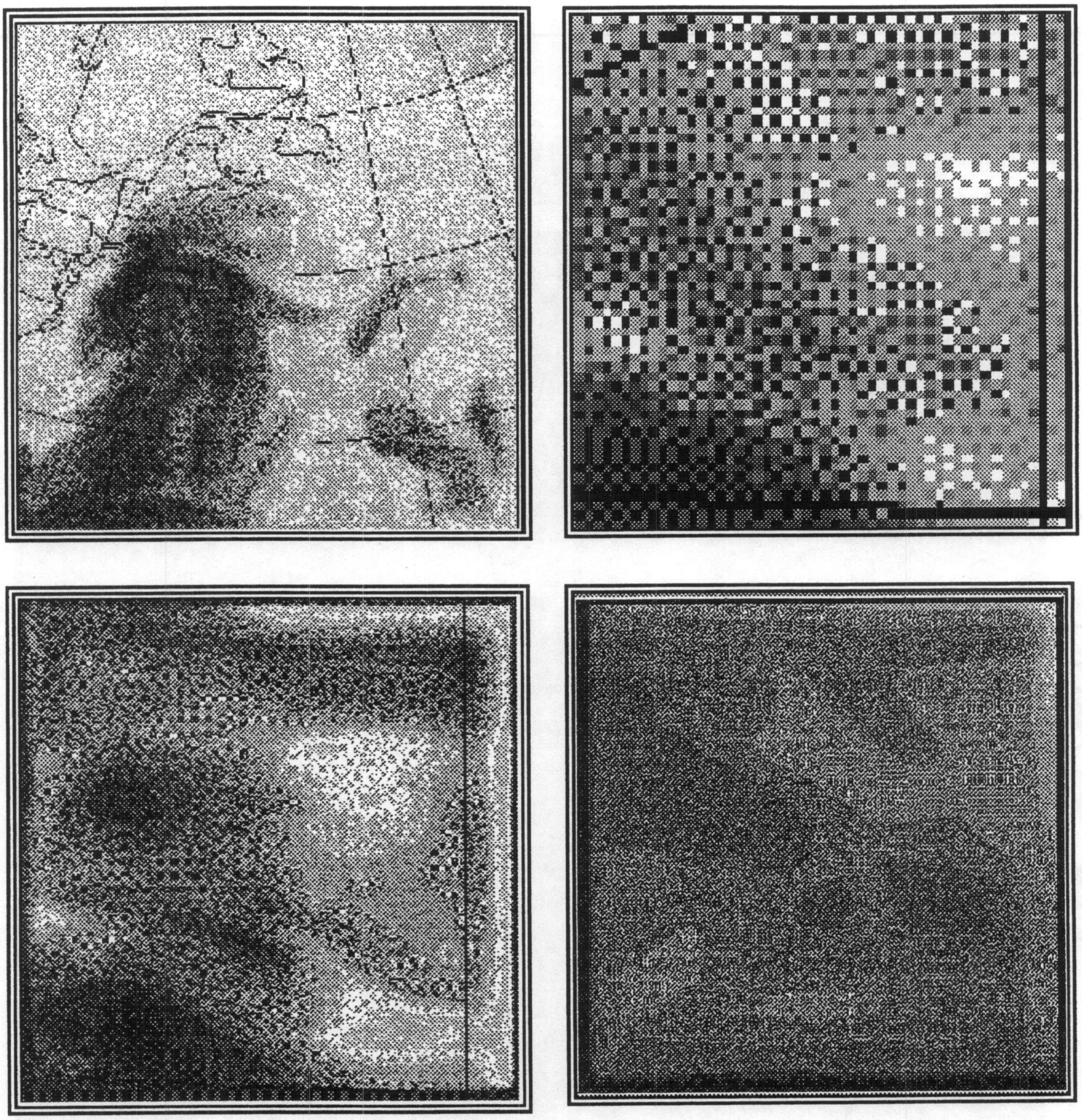


Channel 4

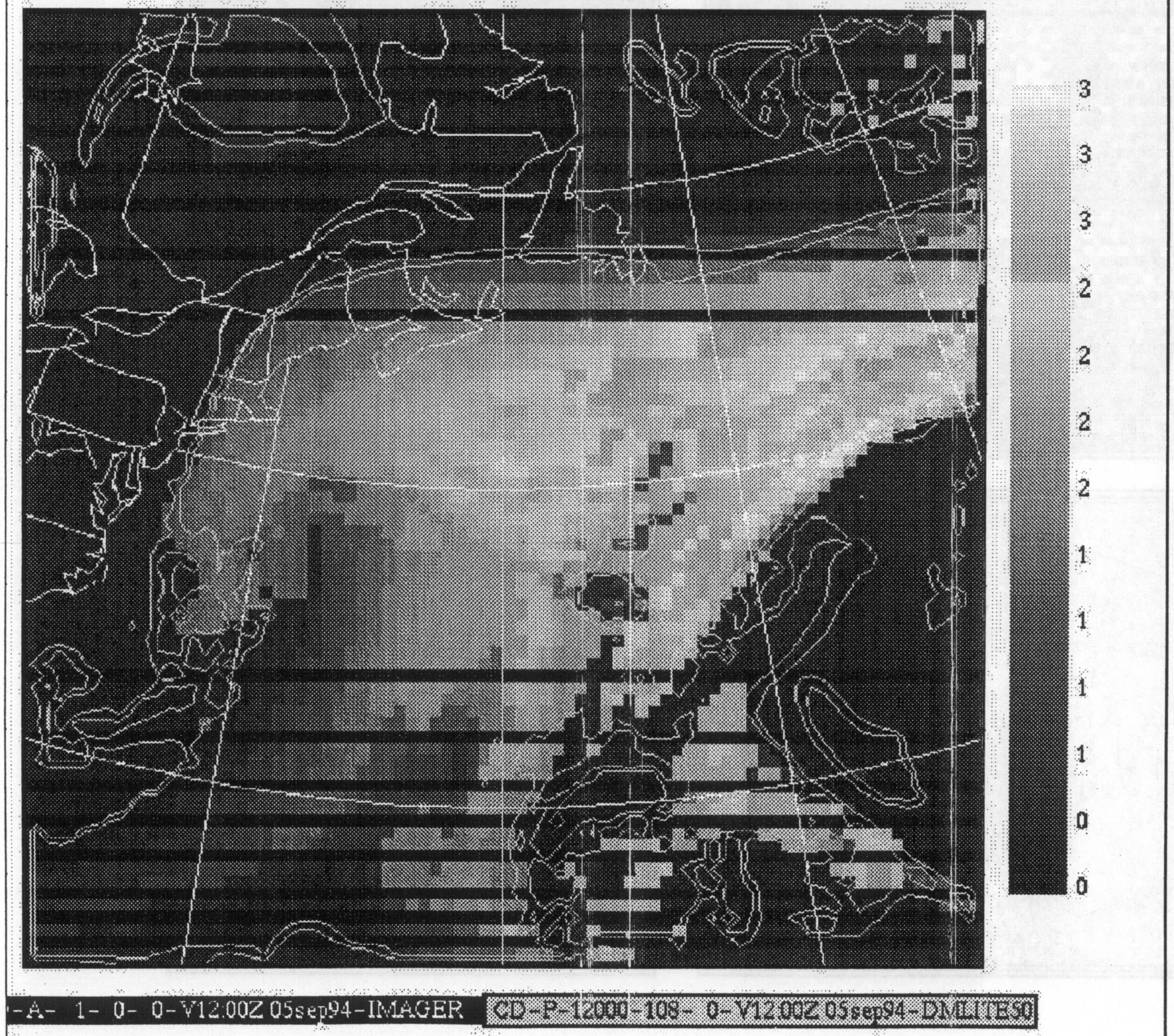


50 KM GRID

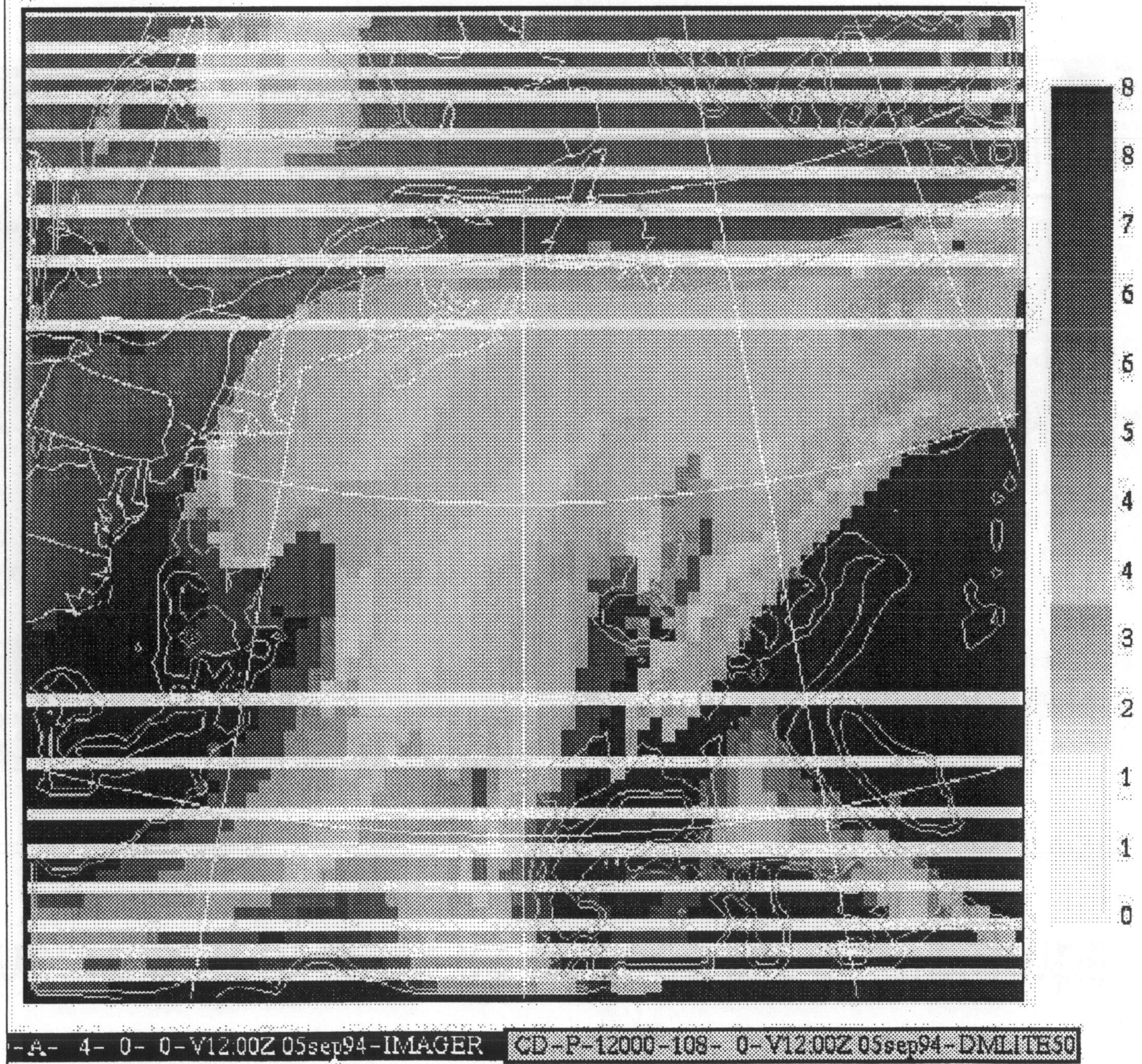
Effect of Scaling from 50km to 7km to 1km resolutions



Vis-Channel 1

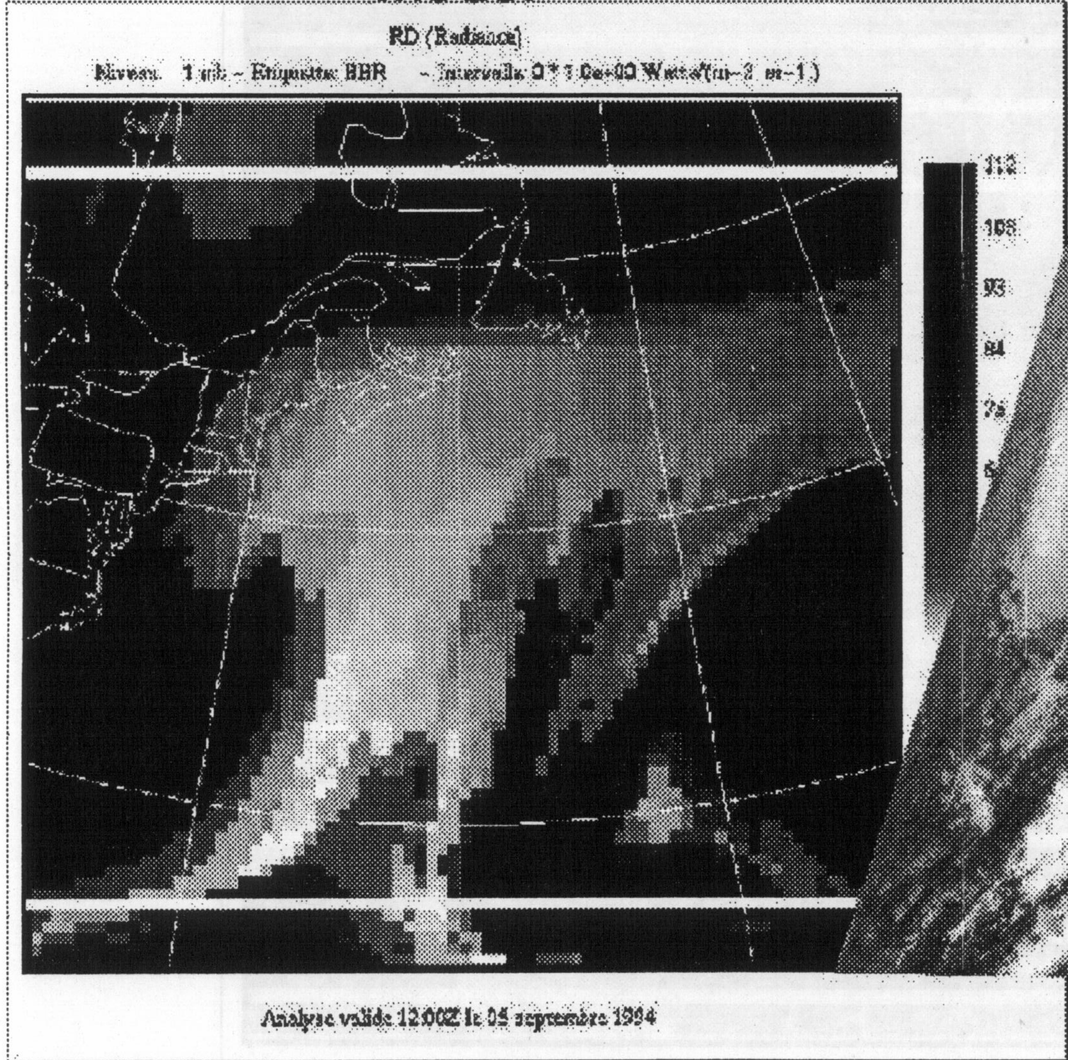


IR-Channel 4

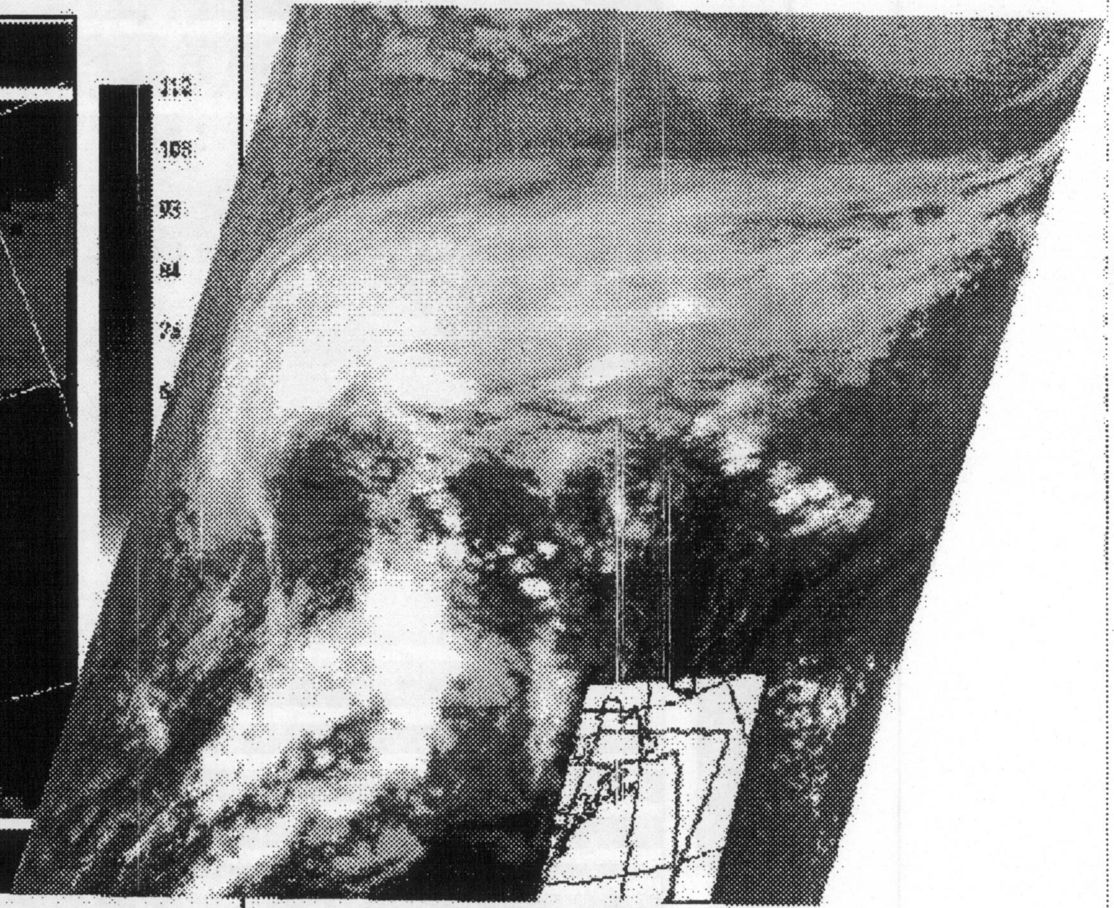

8
8
7
6
6
5
4
4
3
2
1
1
0
-A- 4- 0- 0-V12:00Z 05sep94-IMAGER
CD-P-12000-108- 0-V12:00Z 05sep94-DMLITE50

Comparaison of BBR IR Images for 5 September 1994

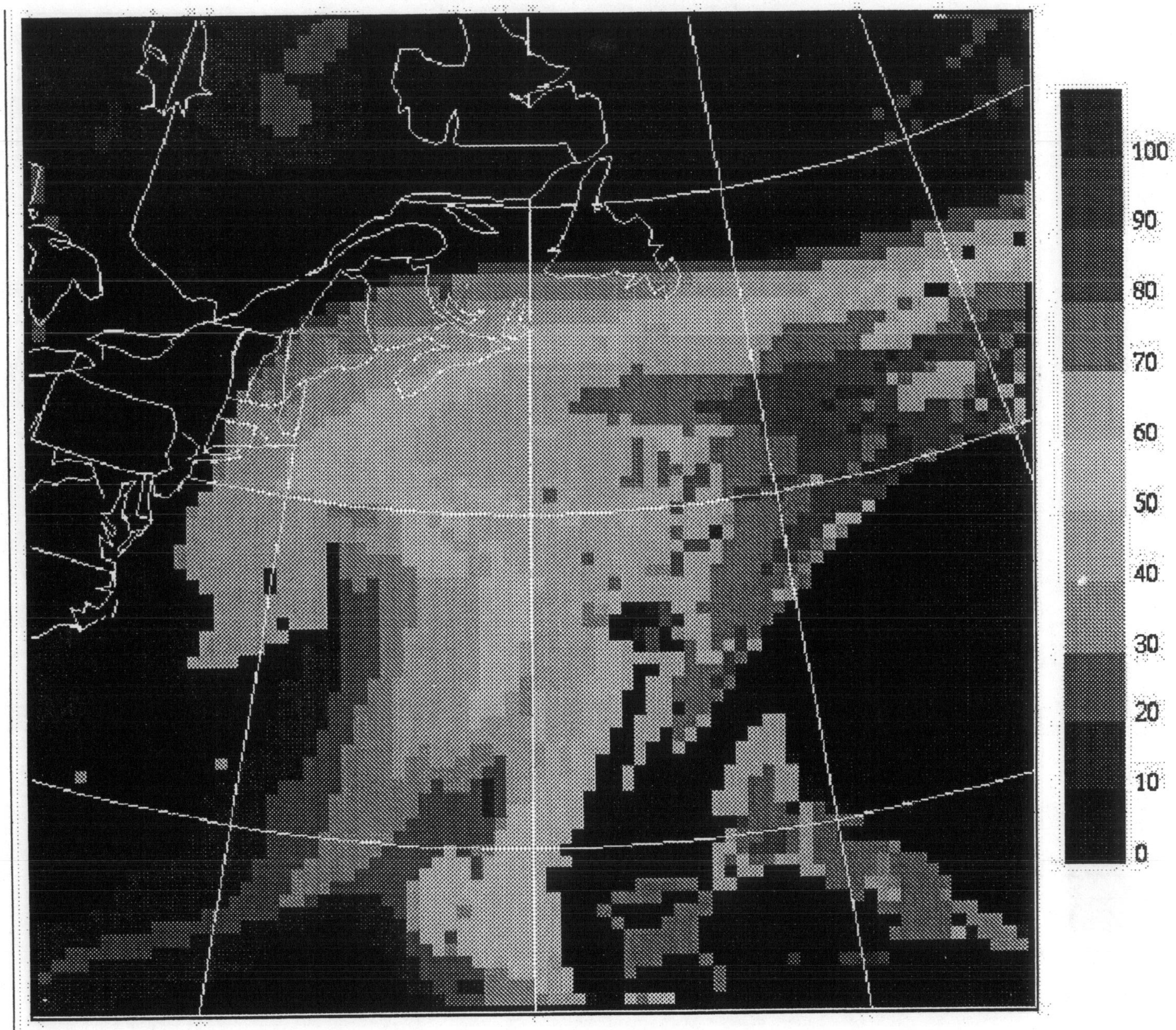
Model



Observed

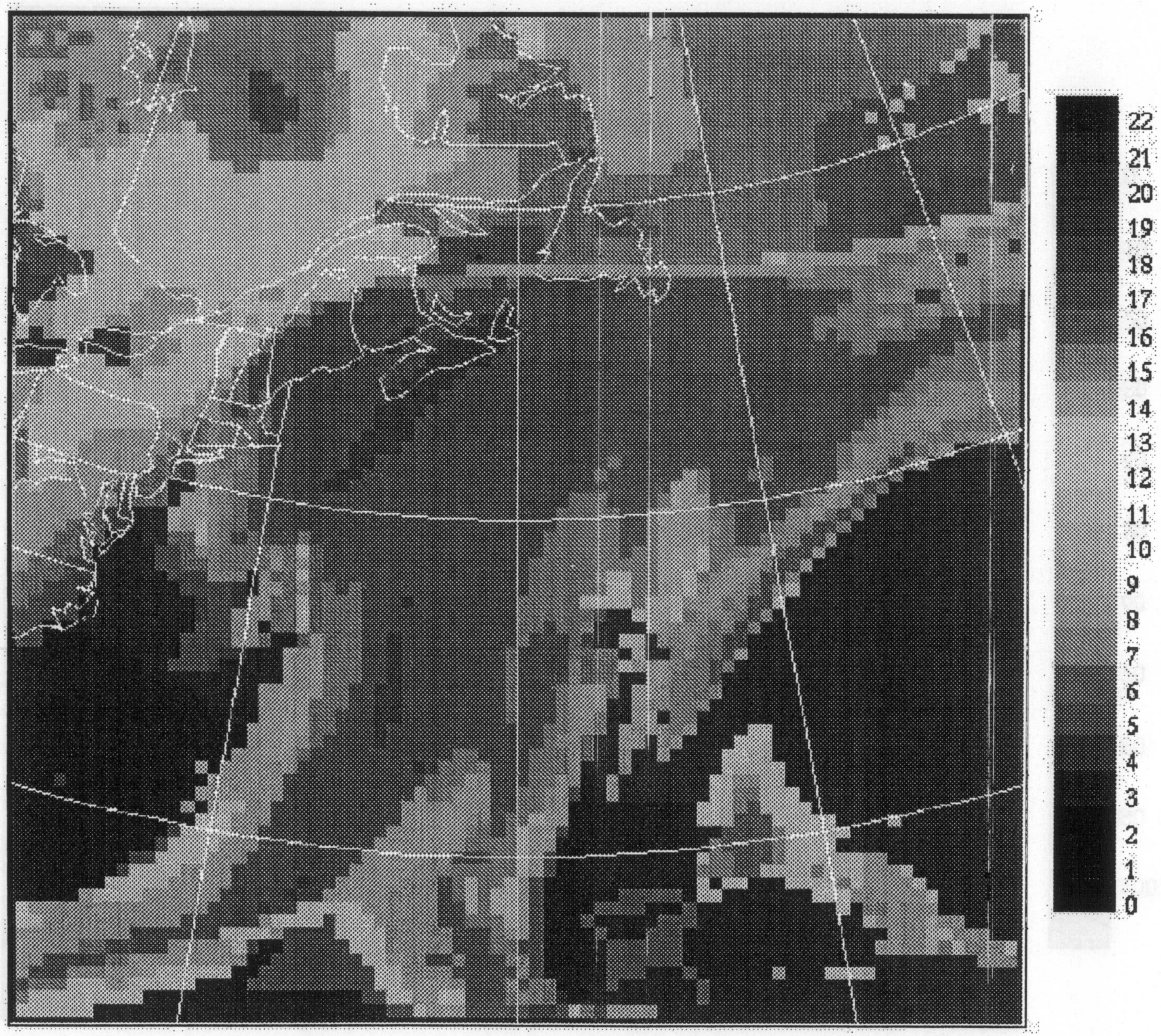


AVHRR channel 1



Analyse valide 12:00Z le 05 septembre 1994

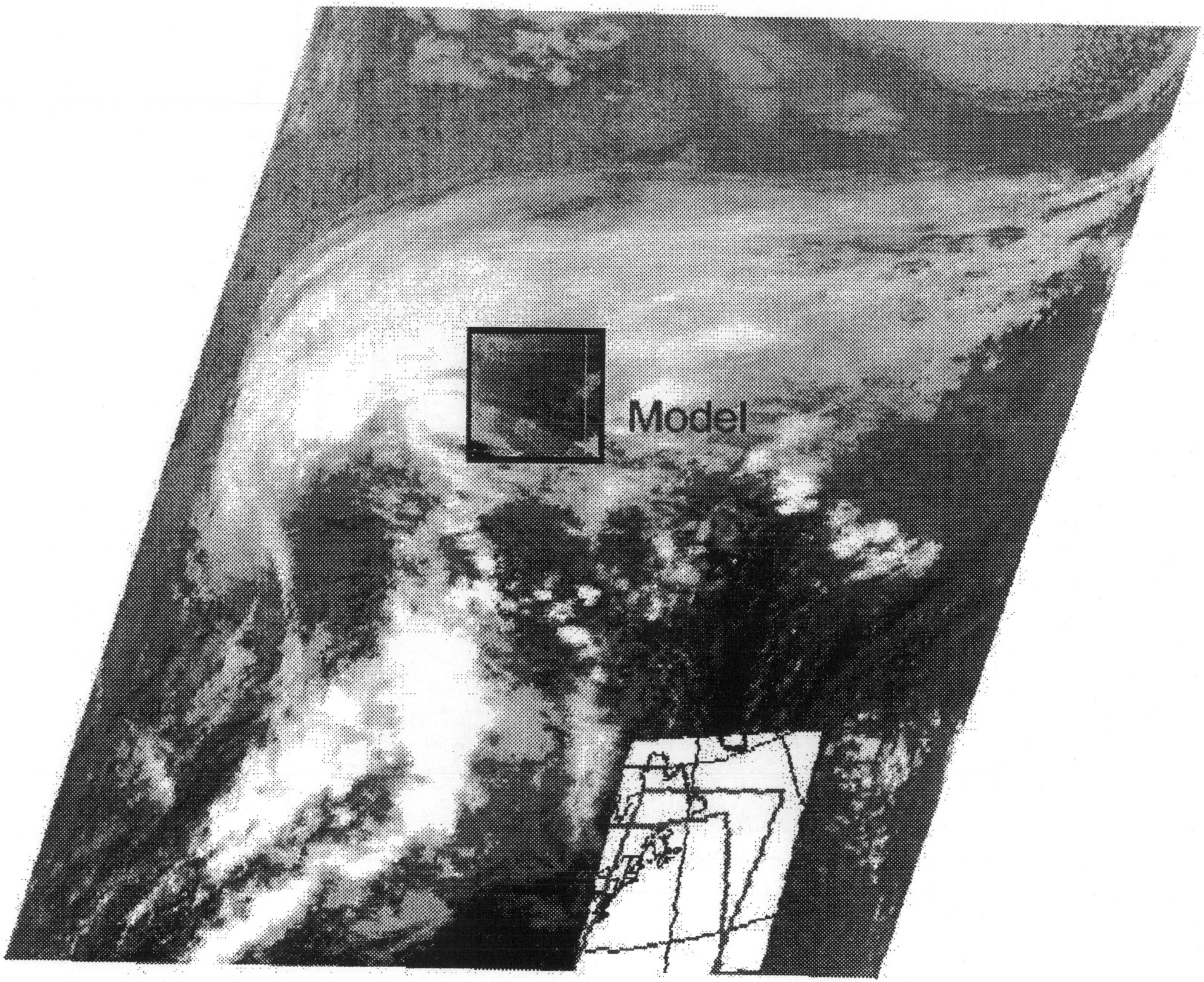
AVHRR channel 4



Analyse valide 12:00Z le 05 septembre 1994

7 KM GRID

Comparaison of the Medium Grid (7km resolution)



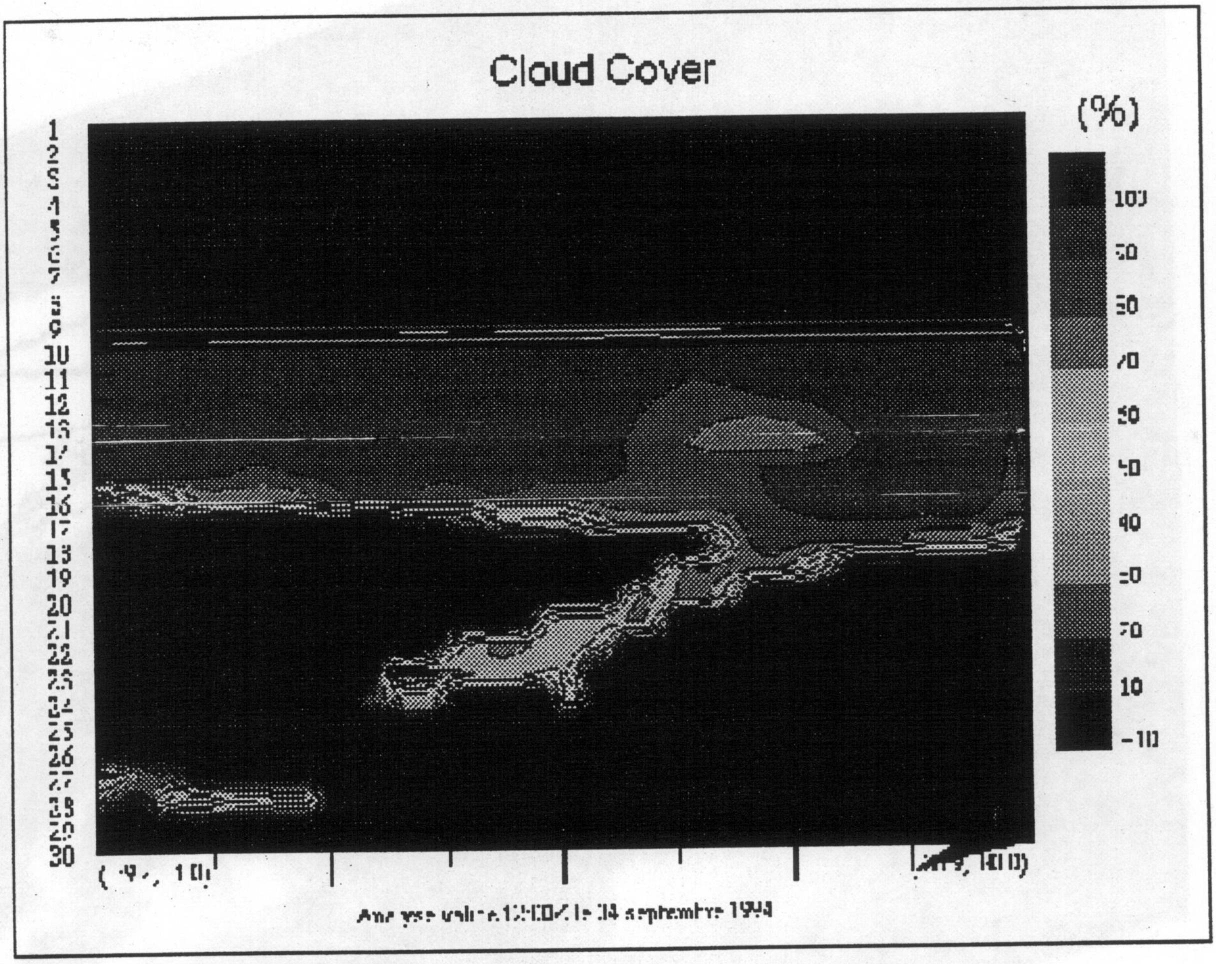
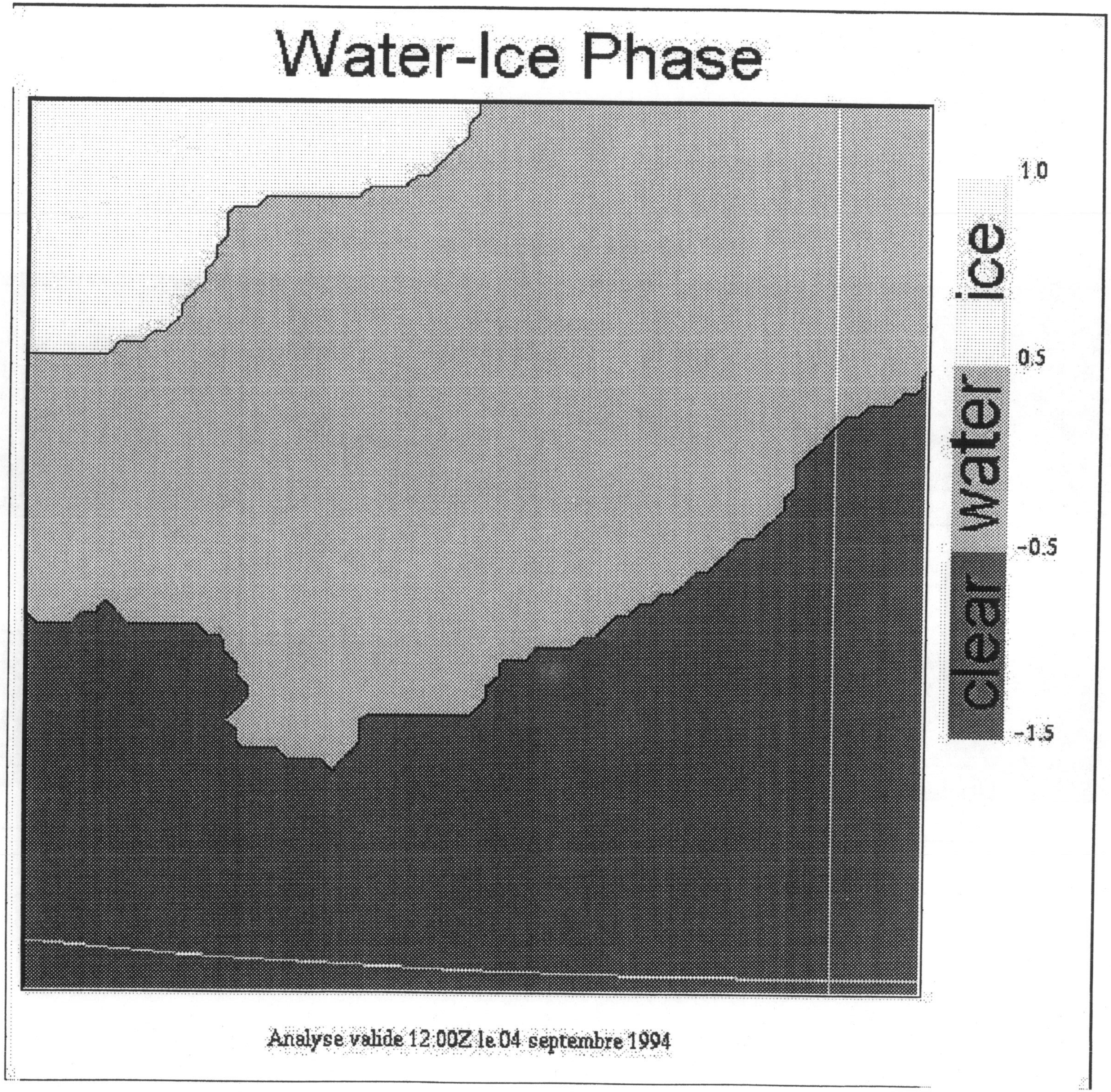
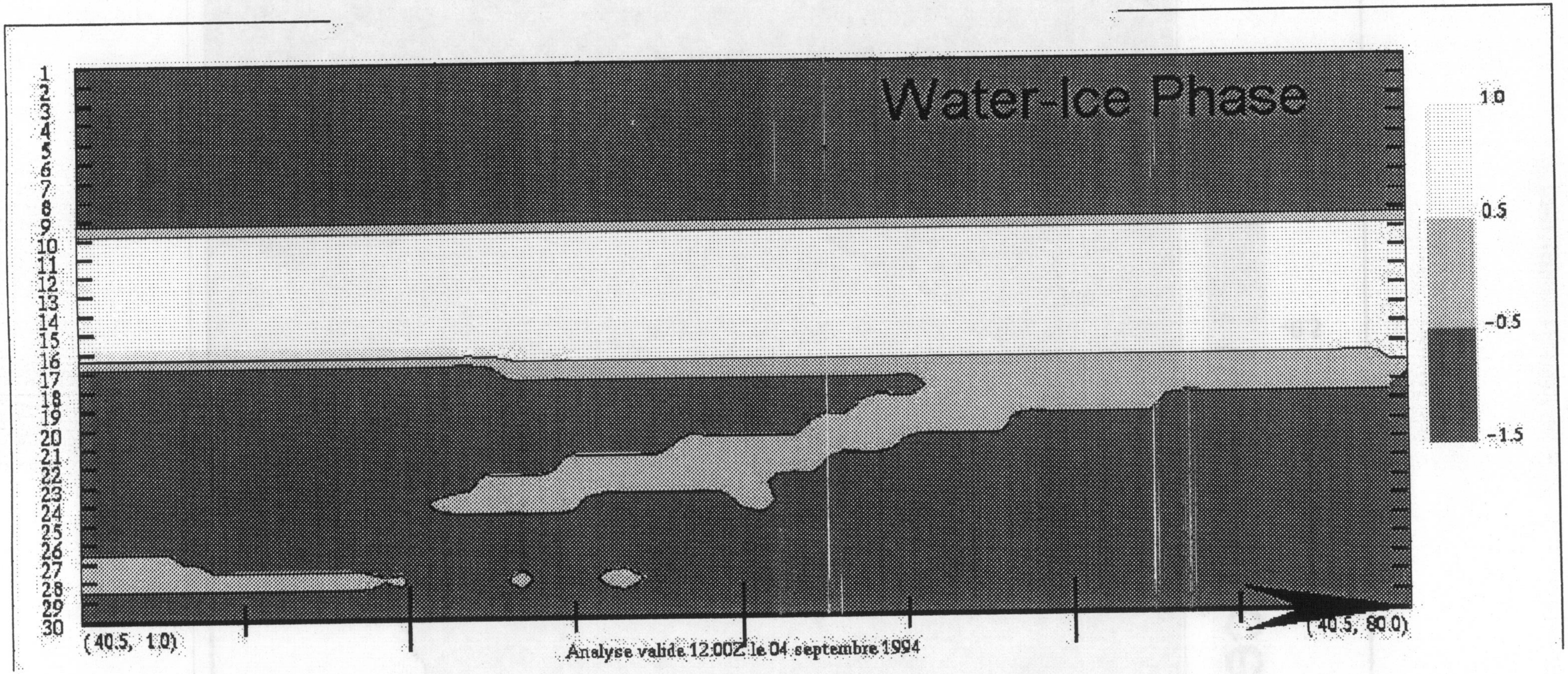


Figure 8. Cross section of cloudiness along the satellite trajectory for the 7 km grid.


Water-Ice Phase
1.0
ice
0.5
water
-0.5
clear
-1.5
Analyse valide 12:00Z le 04 septembre 1994


Water-Ice Phase
1.0
0.5
-0.5
-1.5
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
(40.5, 1.0)
(40.5, 80.0)
Analyse valide 12:00Z le 04 septembre 1994

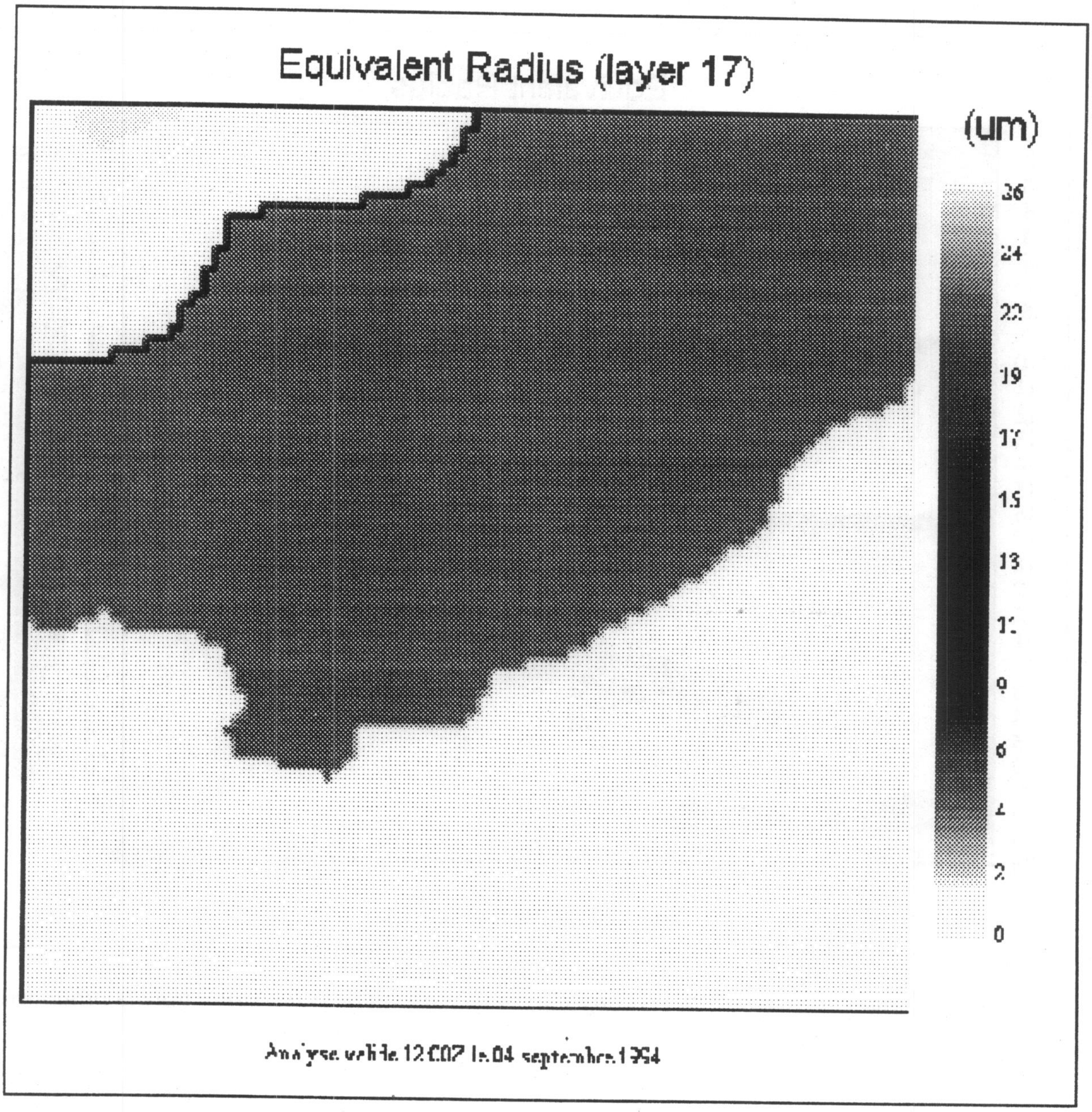


Figure 17. As figure 16 but for equivalent radius.

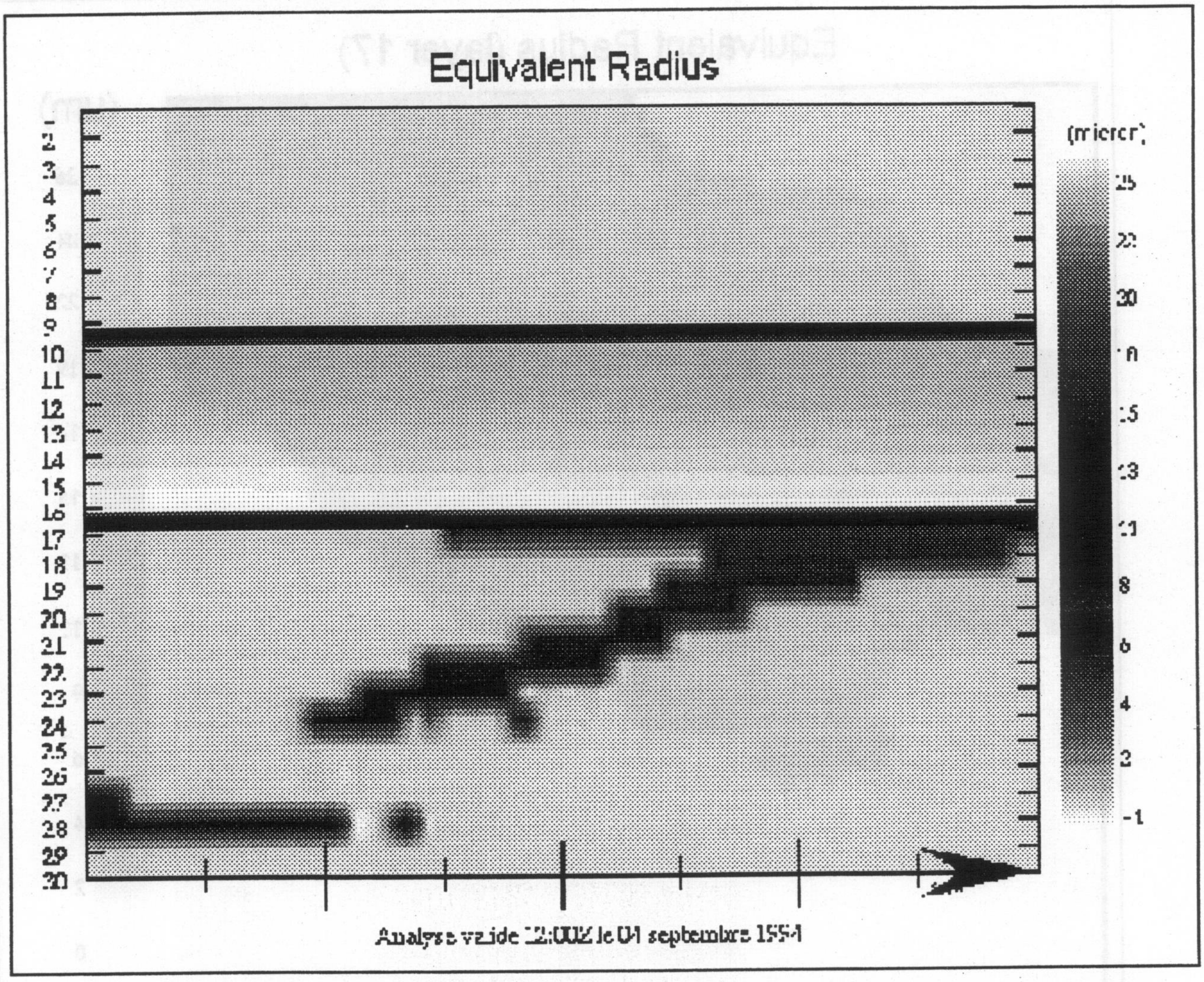


Figure 10. Cloud equivalent radius along the track. Pink color is ice while blue is liquid water.

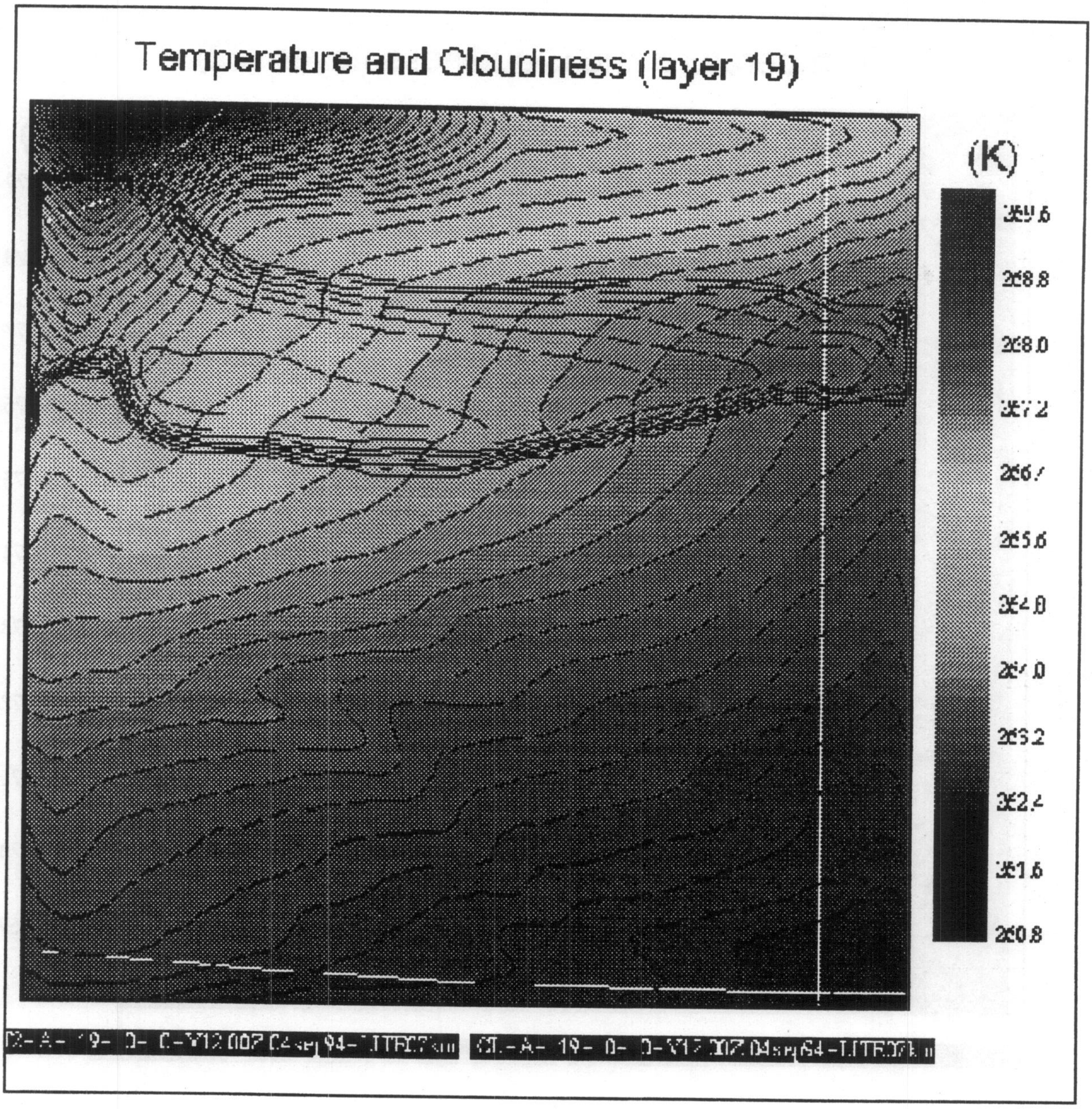


Figure 12. Superposition of temperature field and cloudiness around 4.6 km

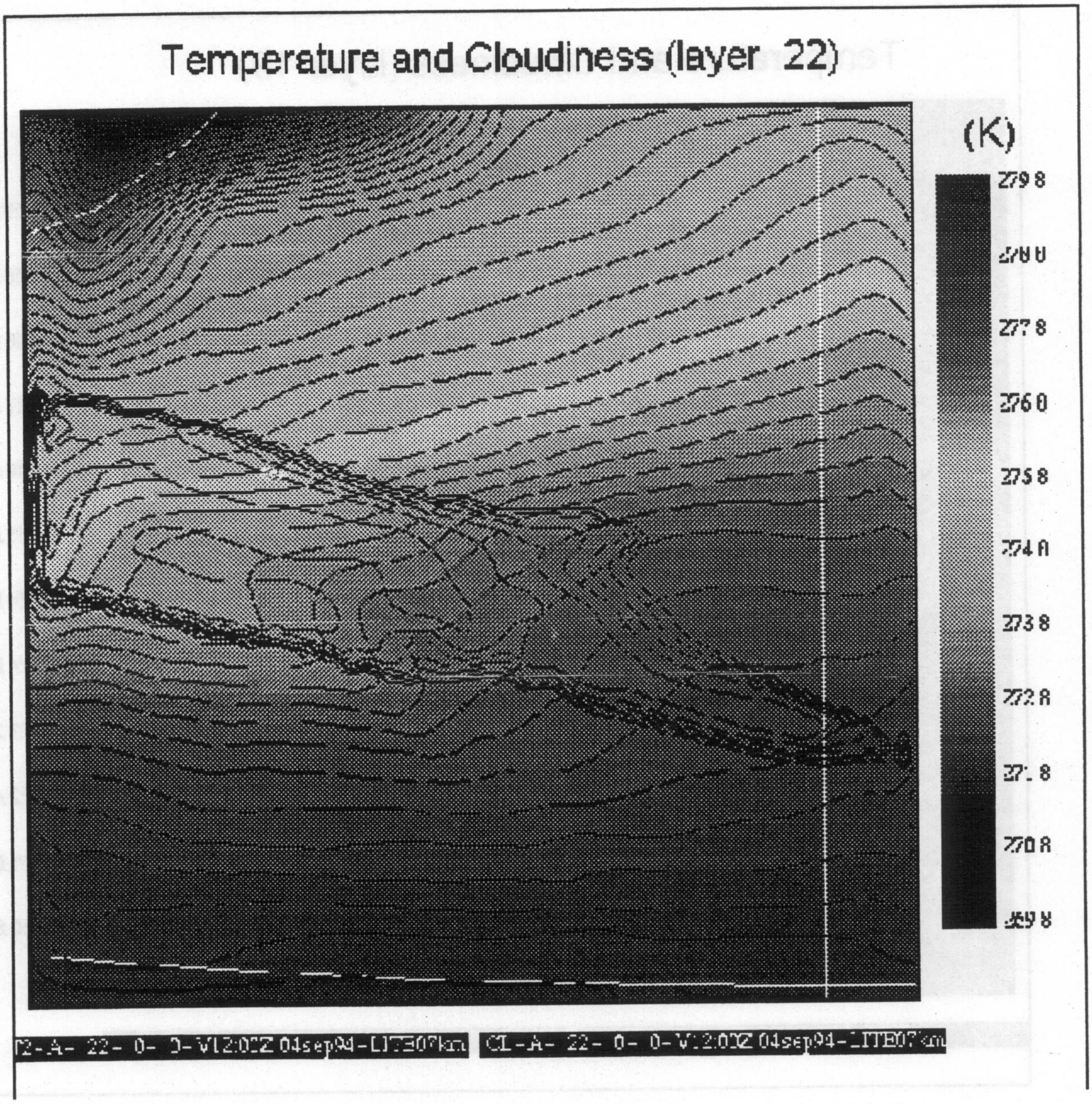


Figure 13. Same as figure 12 but at 2.7 km.

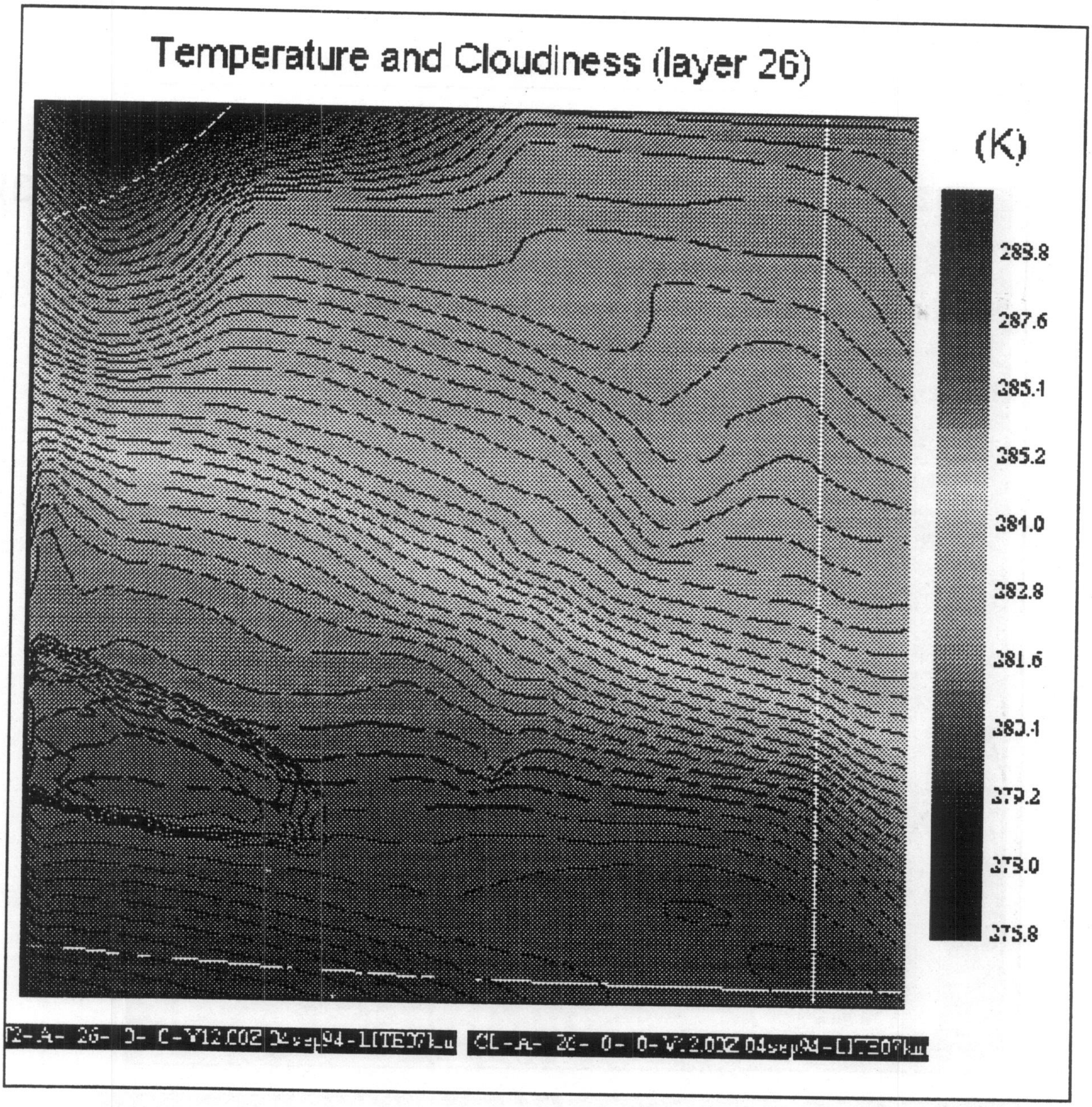


Figure 14. Same as figure 12 but at 1.1 km.

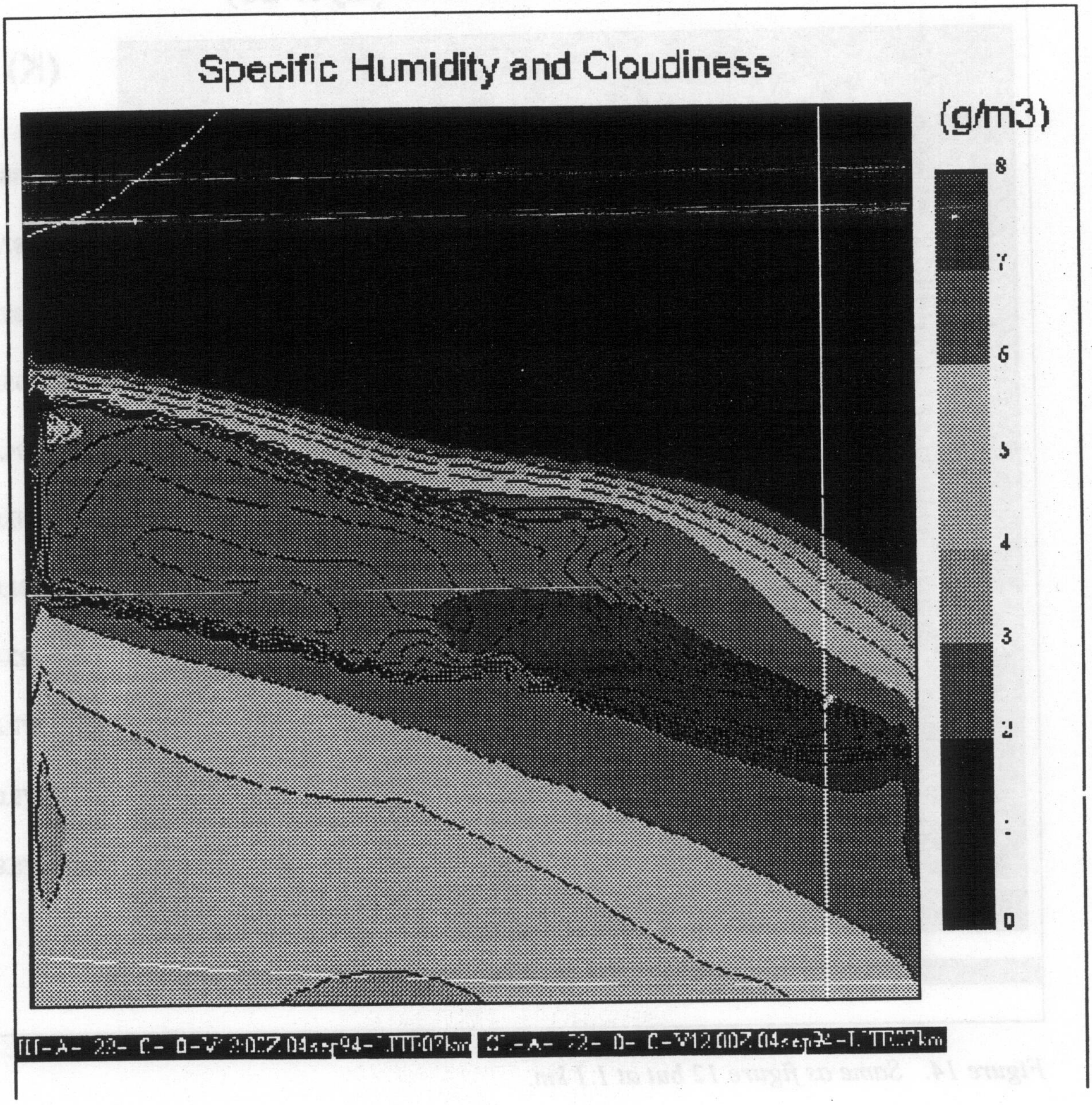


Figure 15. Horizontal change of atmospheric moisture (g.m3) near the warm front.

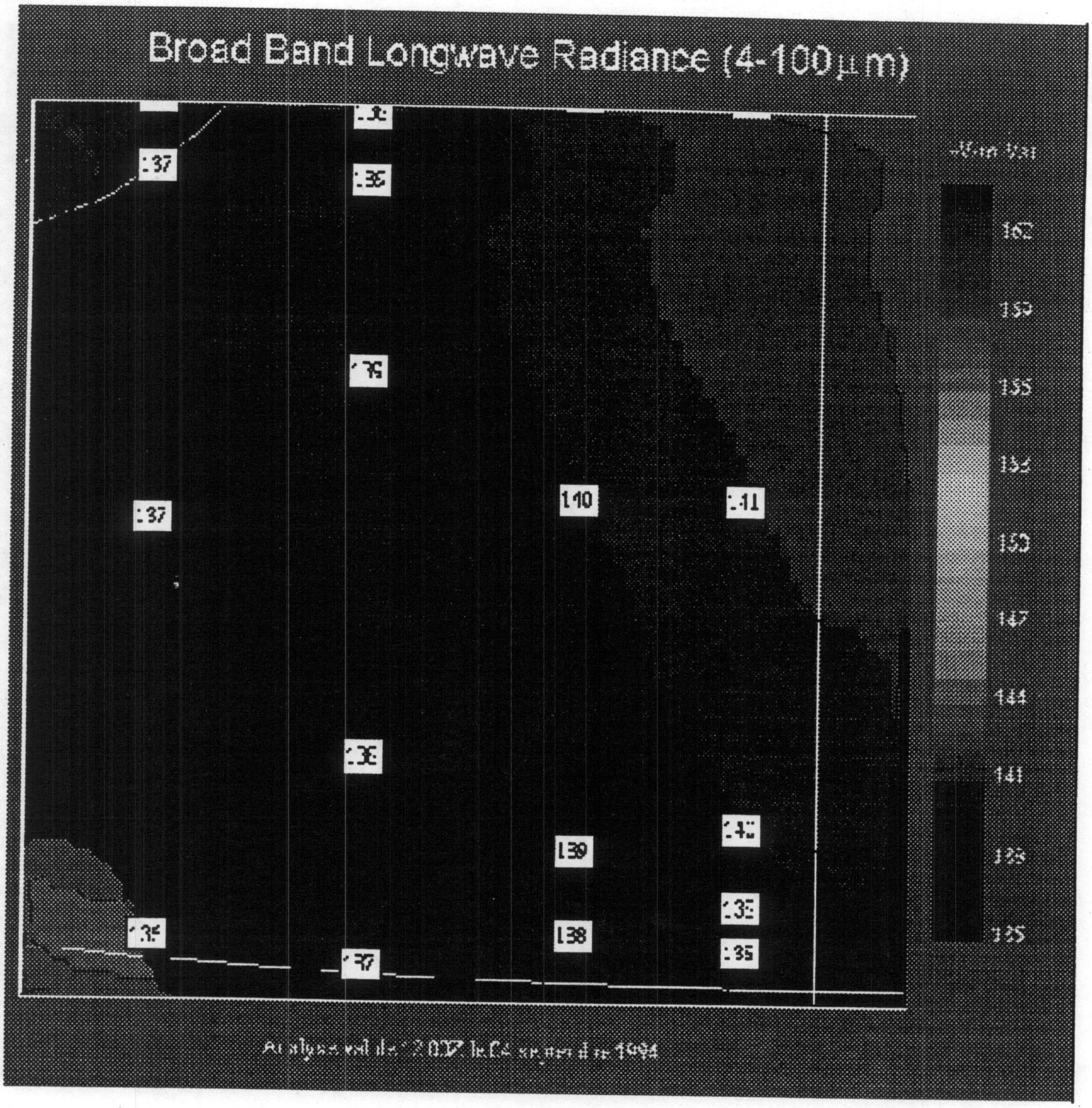


Figure 19. Total IR broad band radiance at the satellite track.

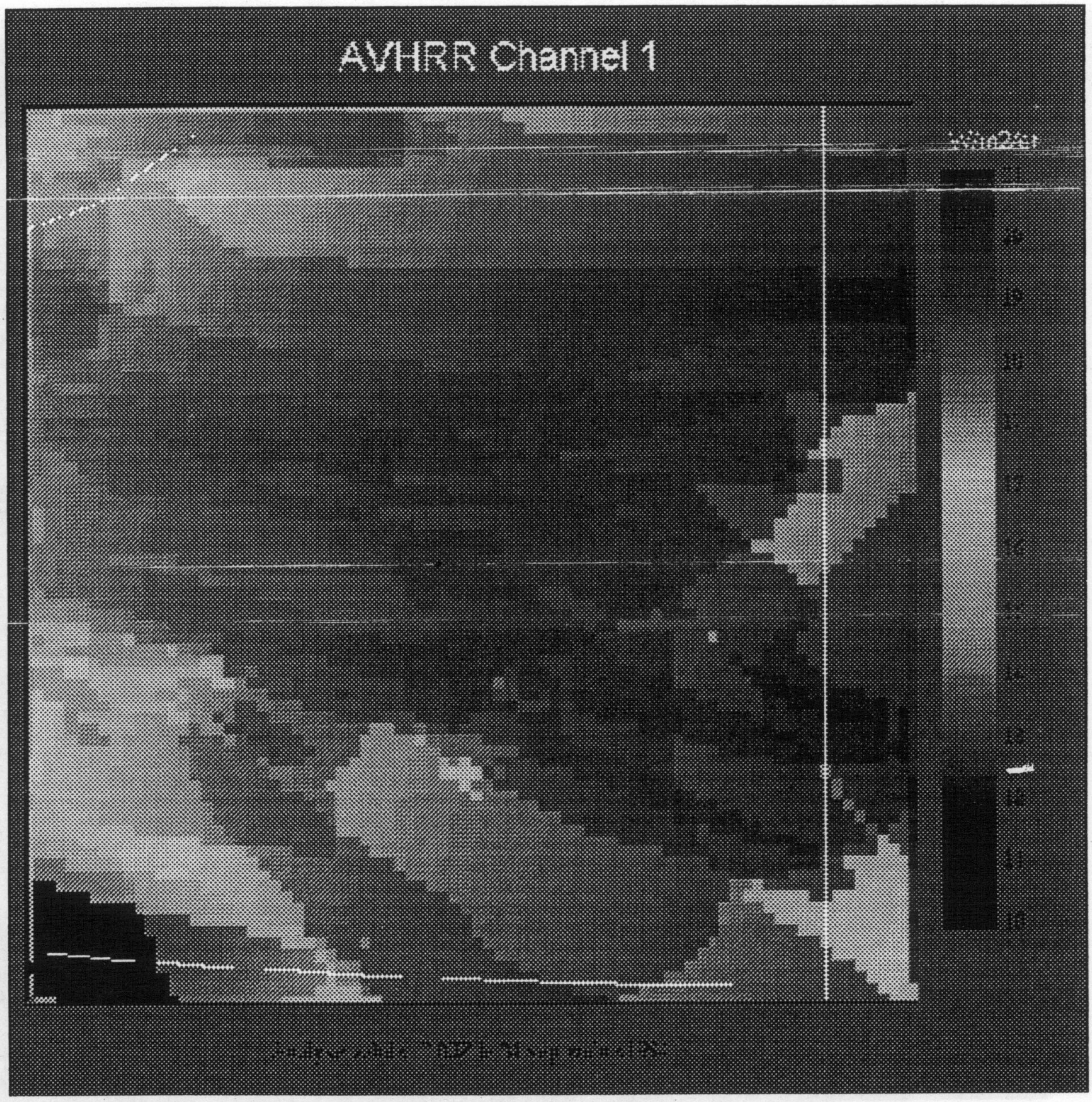


Figure 20. AVHRR channel 1 radiance at the satellite track.

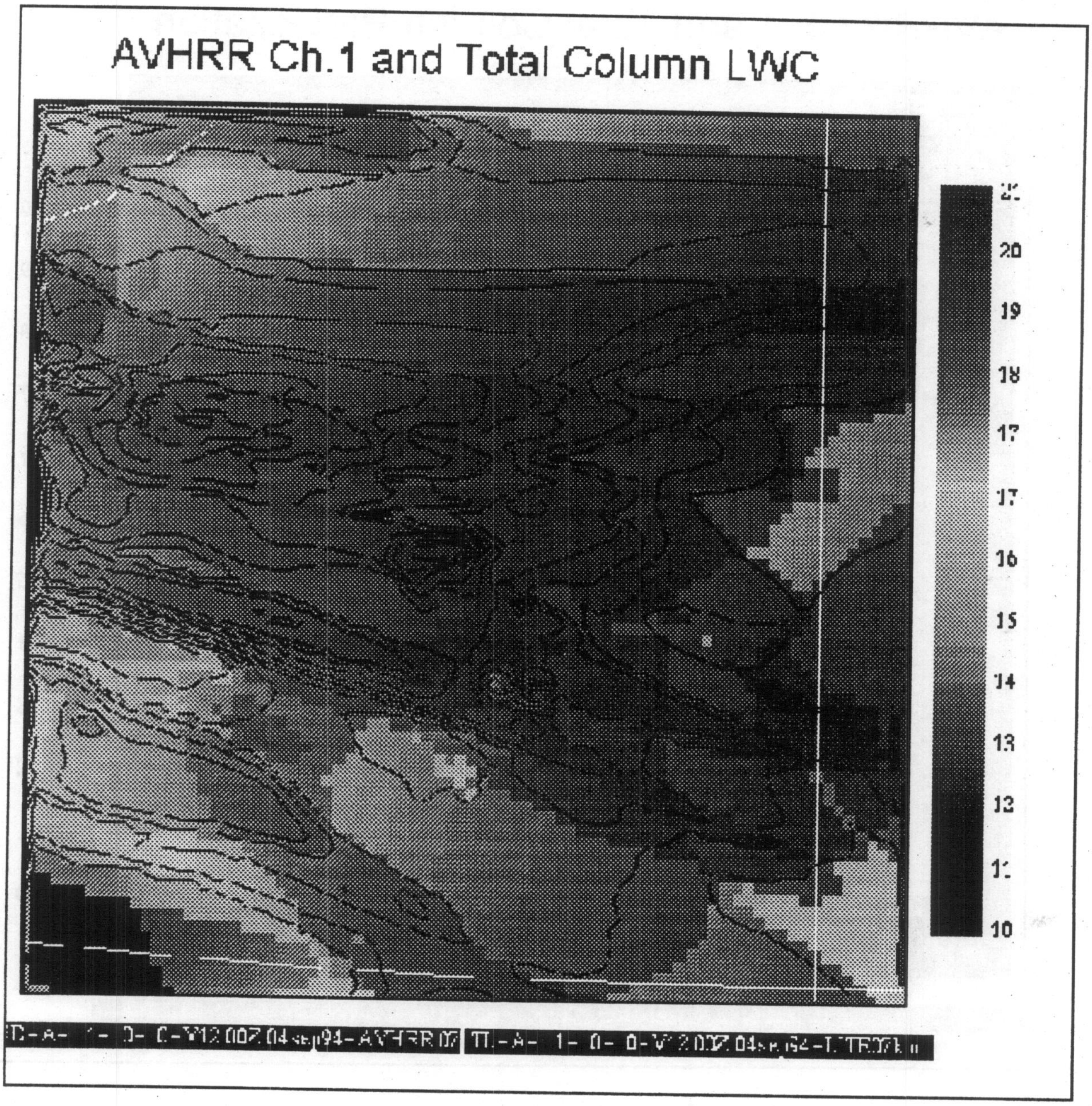


Figure 22. Comparison of AVHRR channel 1 radiance (fig. 20) to total liquid water content.

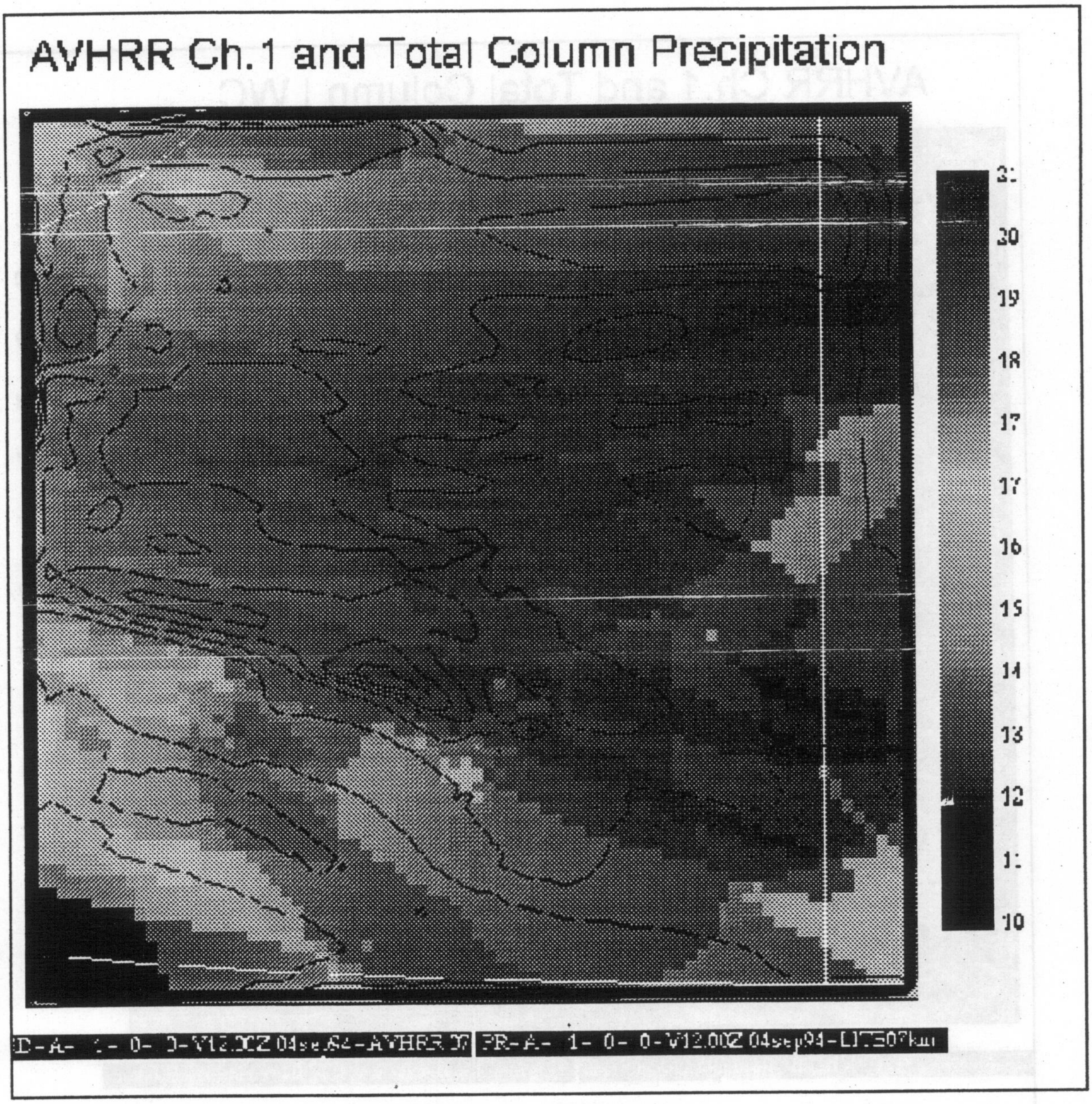


Figure 23. As figure 22 but for precipitation

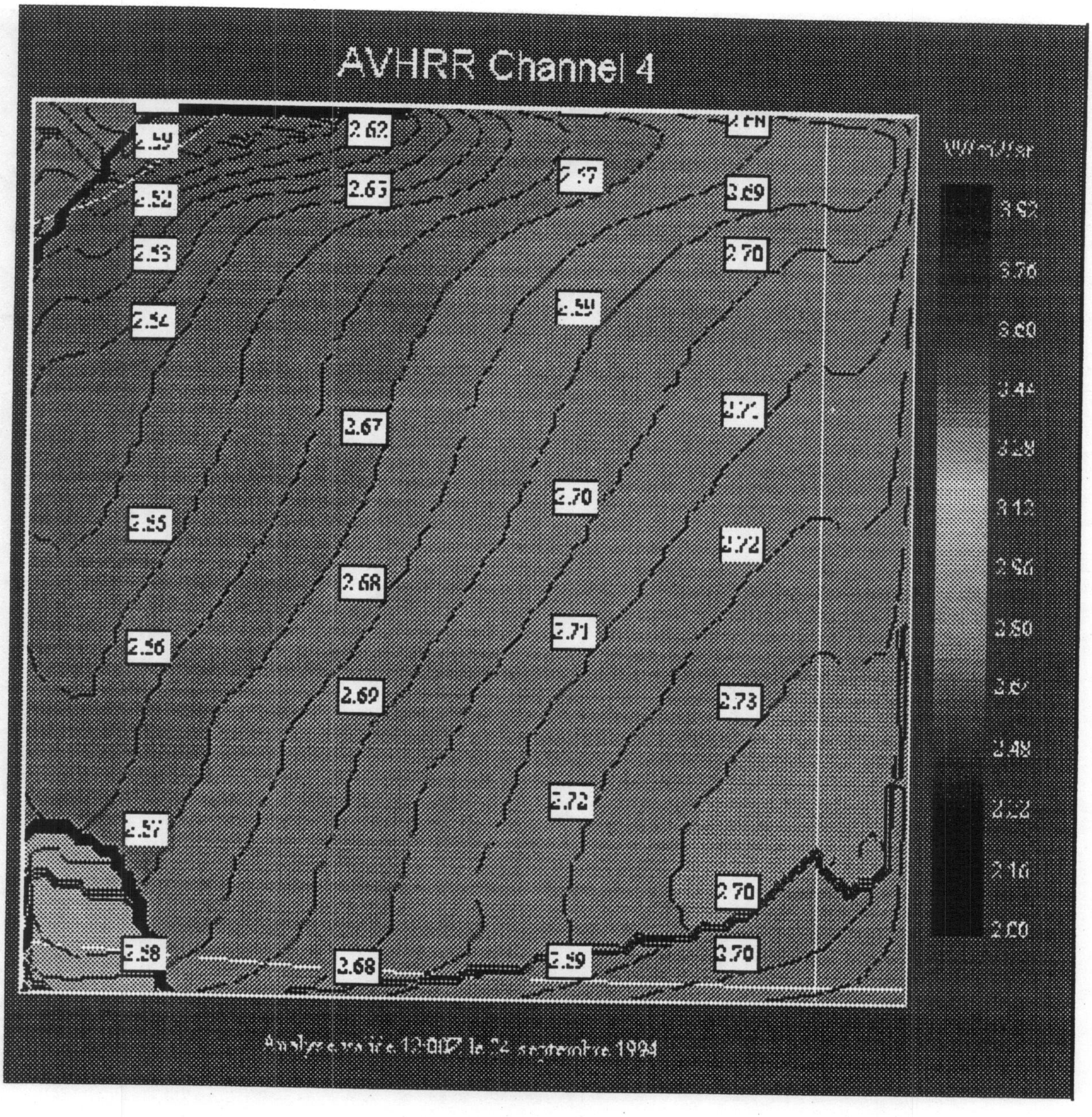


Figure 25. AVHRR channel 4 in the IR at the satellite.

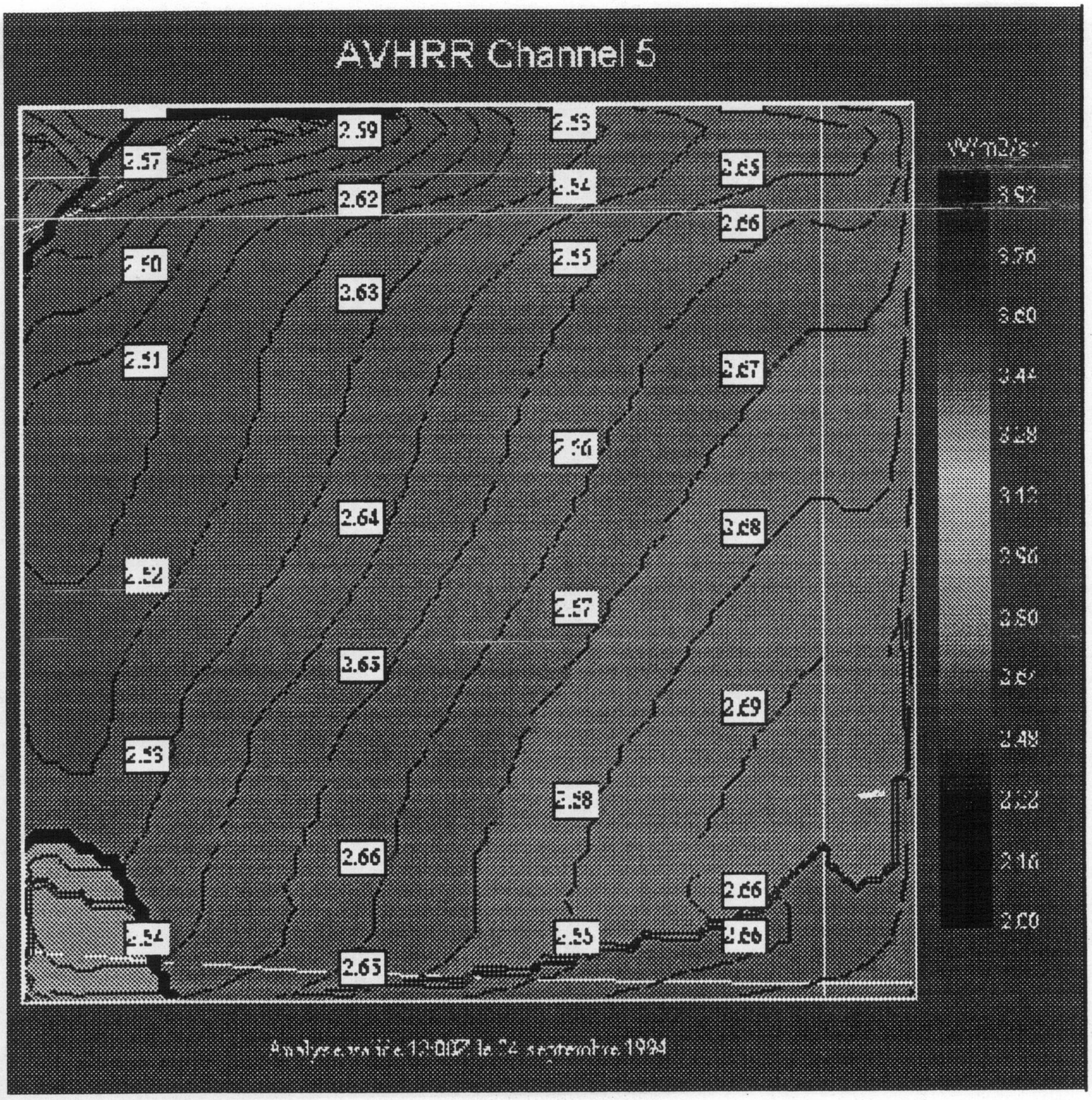
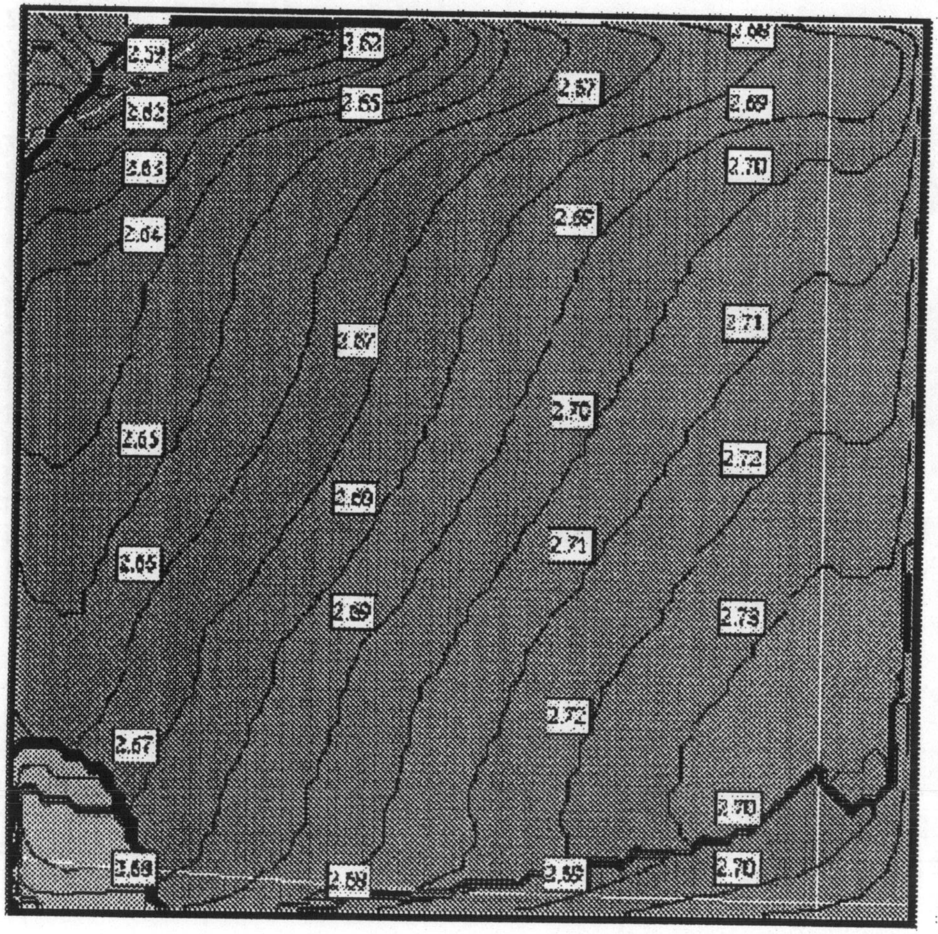
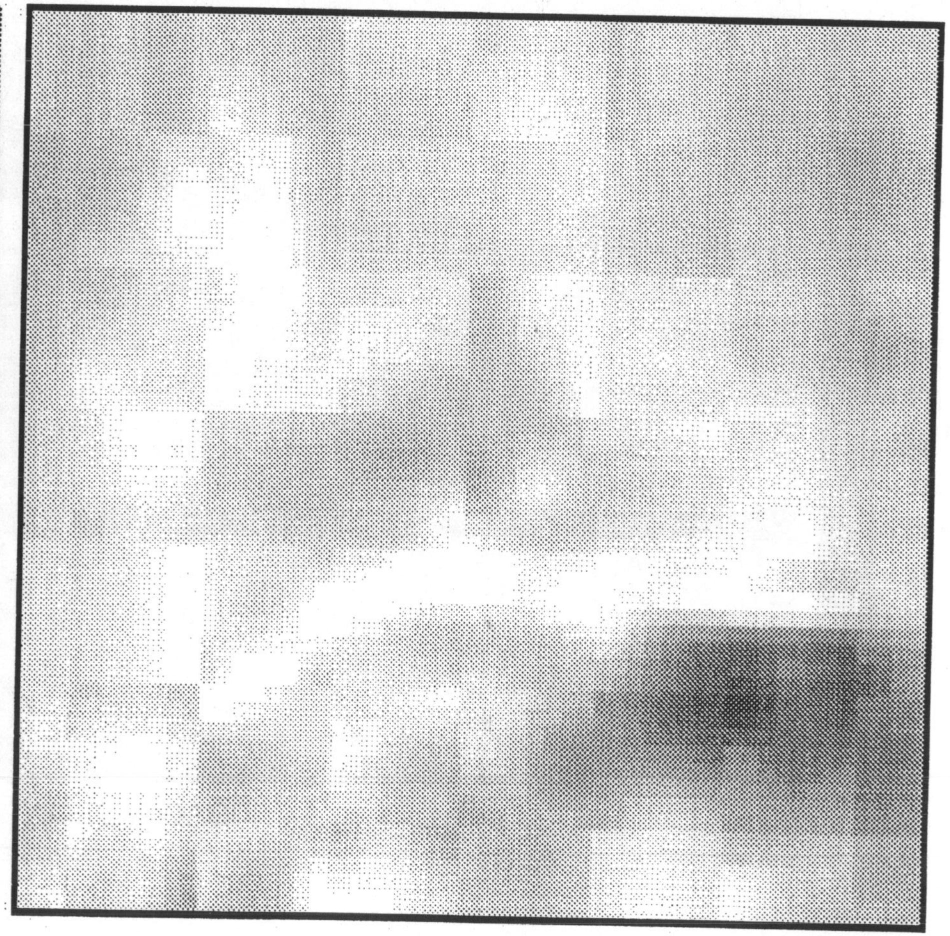
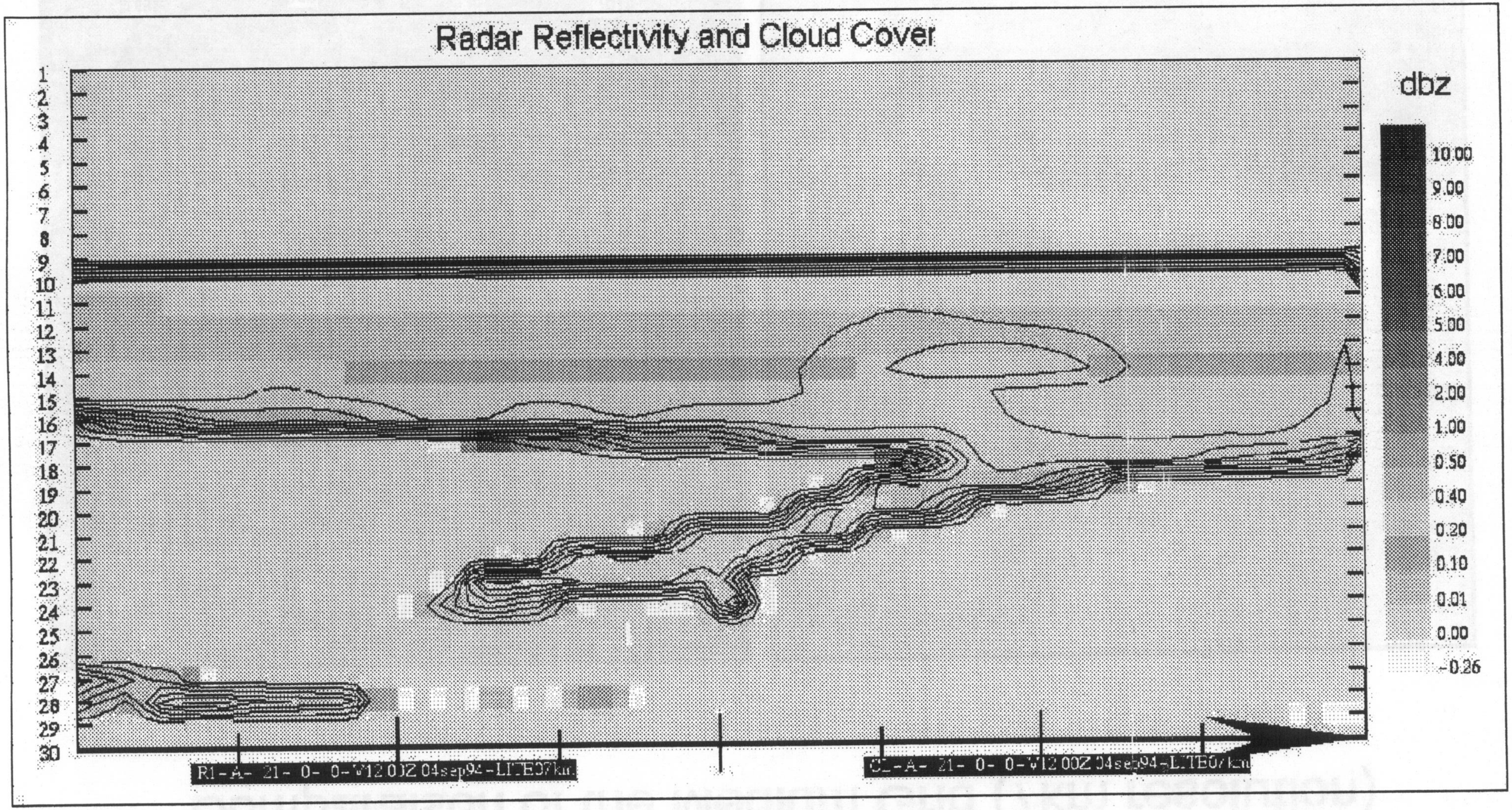


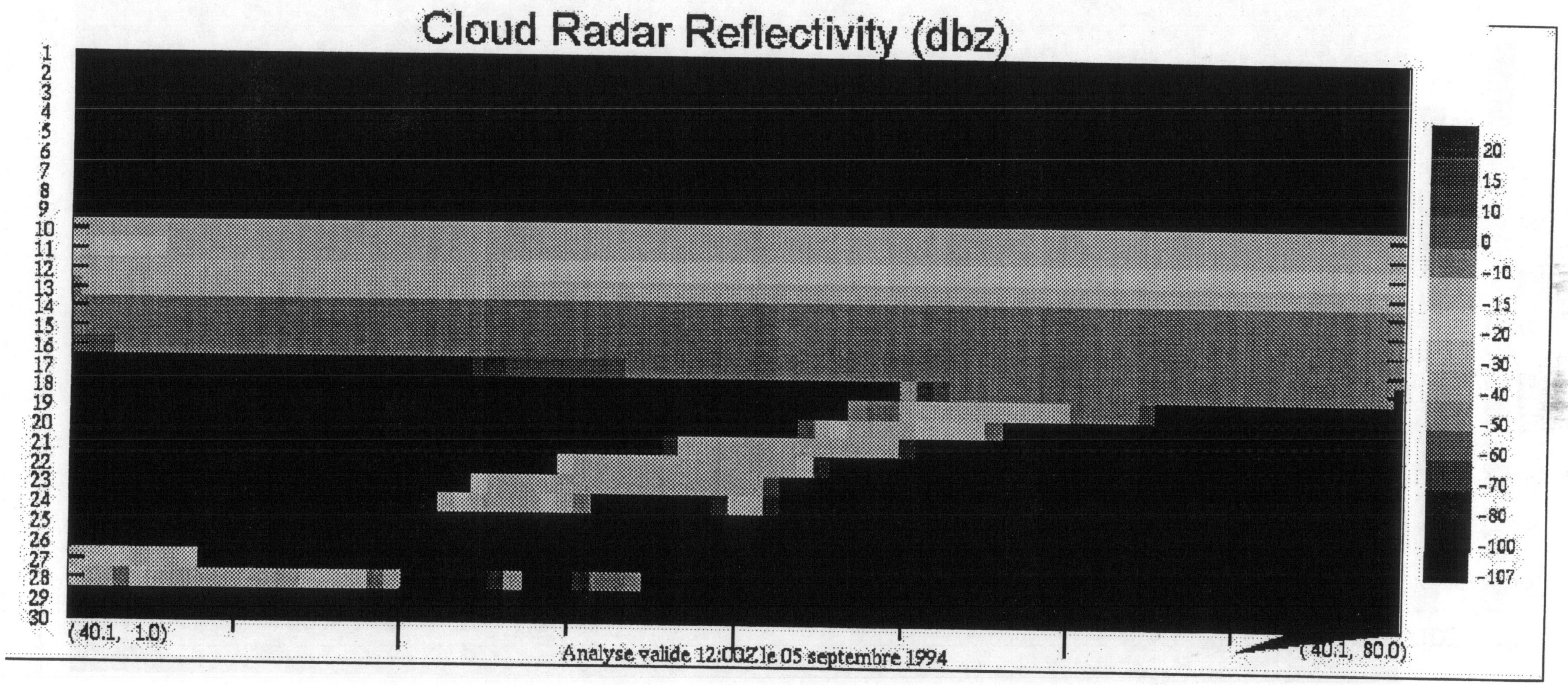
Figure 26. AVHRR channel 5 (IR) at the satellite.

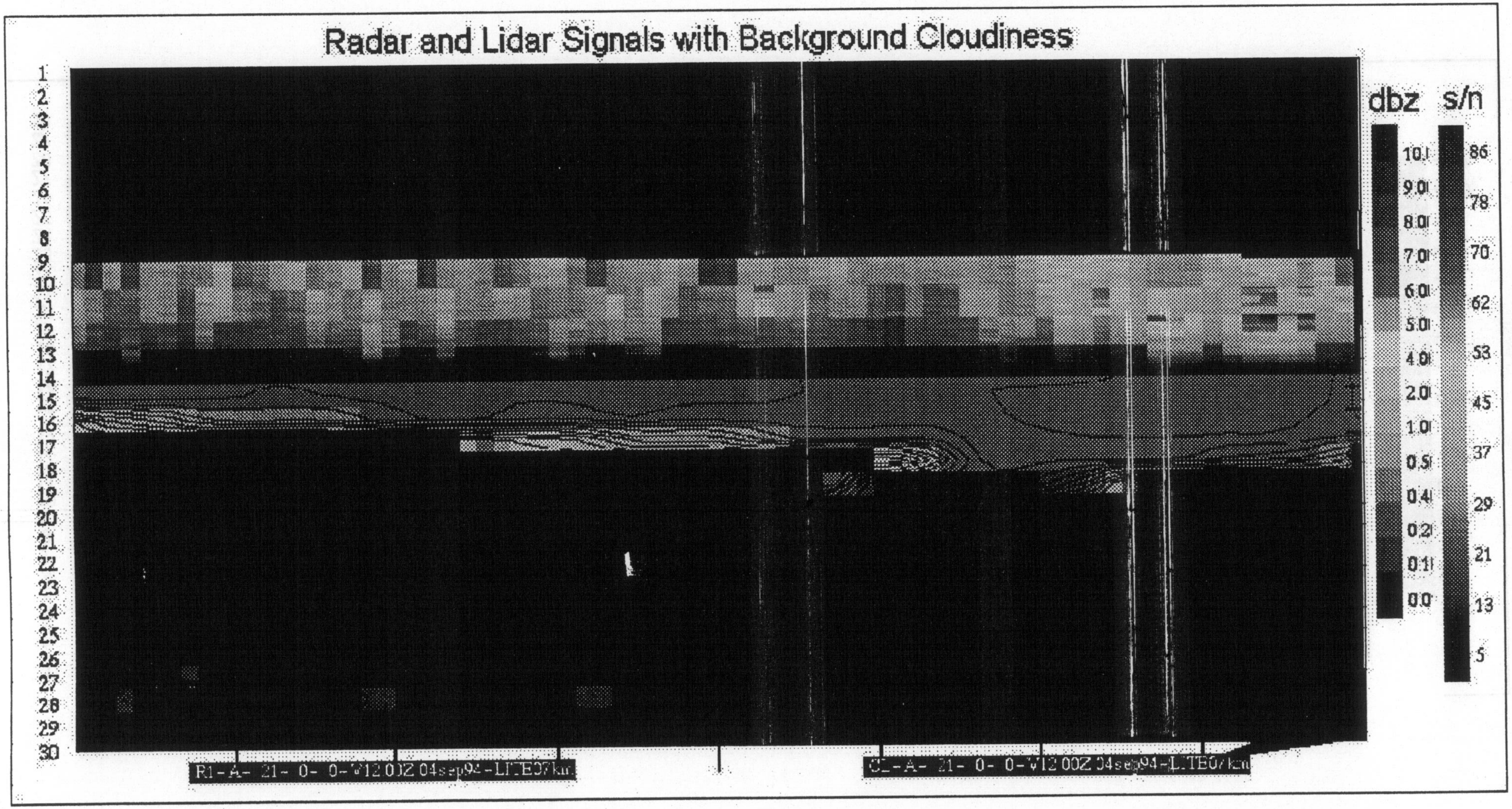
Comparaison of the Medium Grid (7km resolution)






Radar Reflectivity and Cloud Cover
dbz
10.00
9.00
8.00
7.00
6.00
5.00
4.00
2.00
1.00
0.50
0.40
0.20
0.10
0.01
0.00
-0.26
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30


Cloud Radar Reflectivity (dbz)
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
(40.1, 1.0)
(40.1, 80.0)
Analyse valide 12:00Z le 05 septembre 1994
20
15
10
0
-10
-15
-20
-30
-40
-50
-60
-70
-80
-100
-107


Radar and Lidar Signals with Background Cloudiness
dbz
s/n
10.0
9.0
8.0
7.0
6.0
5.0
4.0
2.0
1.0
0.5
0.4
0.2
0.1
0.0
86
78
70
62
53
45
37
29
21
13
5
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30
R1 - A - 21 - 0 - 0 - V12 00Z 04sep94 - LITE07km
CL - A - 21 - 0 - 0 - V12 00Z 04sep94 - LITE07km

Summary

Part 1 : Input Data Set

- The Canadian Regional Climate Model is used in forecast mode to generate samples of the atmospheric states applicable to drive the SYPAI simulator on realistic conditions.
- A cloud microphysics model is applied to generate cloud properties from the RCM prognostic variables.
- The cloud system is dependent on physical process formation : radiation, condensation, water phase, precipitation, entrainment-detainment, transport, evaporation, . . .
  and scale dependent processes : convection, stratiform Rossby wave, mesoscale systems, orographic induced clouds, . . .
- A new step in the climate model includes aerosol microphysics (NARCM) that is interactive with cloud microphysics and radiation.

Part 2 : SYPAI Simulation Tool

- For efficiency, SYPAI is run in two steps
  - STREAMER/DISORT to compute spectral radiance field
  - Passive and active instruments in forward mode to compute instrument signals.
- Each scene can be recomputed quickly for any instrument setup scenario.
- This project can lead us to the simulation of a comprehensive aerosol-cloud-radiation synergy study for which the LITE experiment shows encouraging results and significance for climate.

I. THE UNDERLYING SCIENCE

ANALYSIS OF ERM SYNERGY BY USE OF CLARA OBSERVATIONS

A. VAN LAMMEREN, KNMI

Analysis of ERM synergy by use of CLARA observations

Andre van Lammeren

Koninklijk Nederlands Meteorologisch Instituut

KNMI

Contents

- Goal of this study
- Introduction to CLARA
- Contents of the study
- Status (recent results)
- Concluding remarks

Goal of this study

…..This project aims to optimize the sensor synergy. More specifically, the synergy between CPR and lidar will be investigated. The observations will be used to derive macro- and if possible also microphysical cloud properties. ……...

CLARA Instrumentation

- **Lidars:** **1064, 532, 906 nm (RIVM, KNMI, ESTEC)**
- **Radar:** **3 GHz (IRCTR/TUD)**
- **Microwave Radiometer: 20/30/50GHz (TUE, ESTEC)**
- **IR-radiometer: 9.6 - 11.5 micro m (KNMI)**
- **Radiosondes (KNMI, IRCTR/TUD, TUE)**
- **GPS-receiver (TUD/Geodesy)**
- **Visual and IR-video (KNMI, TNO)**
- **Cloud Detection System (KNMI)**

CLARA Instrumentation II

- **Aircraft**
  - **FSSP (ECN)**
- **Satellite**
  - **AVHRR (KNMI)**
  - **Meteosat (KNMI)**
  - **ATSR (RAL, KNMI)**
  - **Gome (KNMI, SRON)**

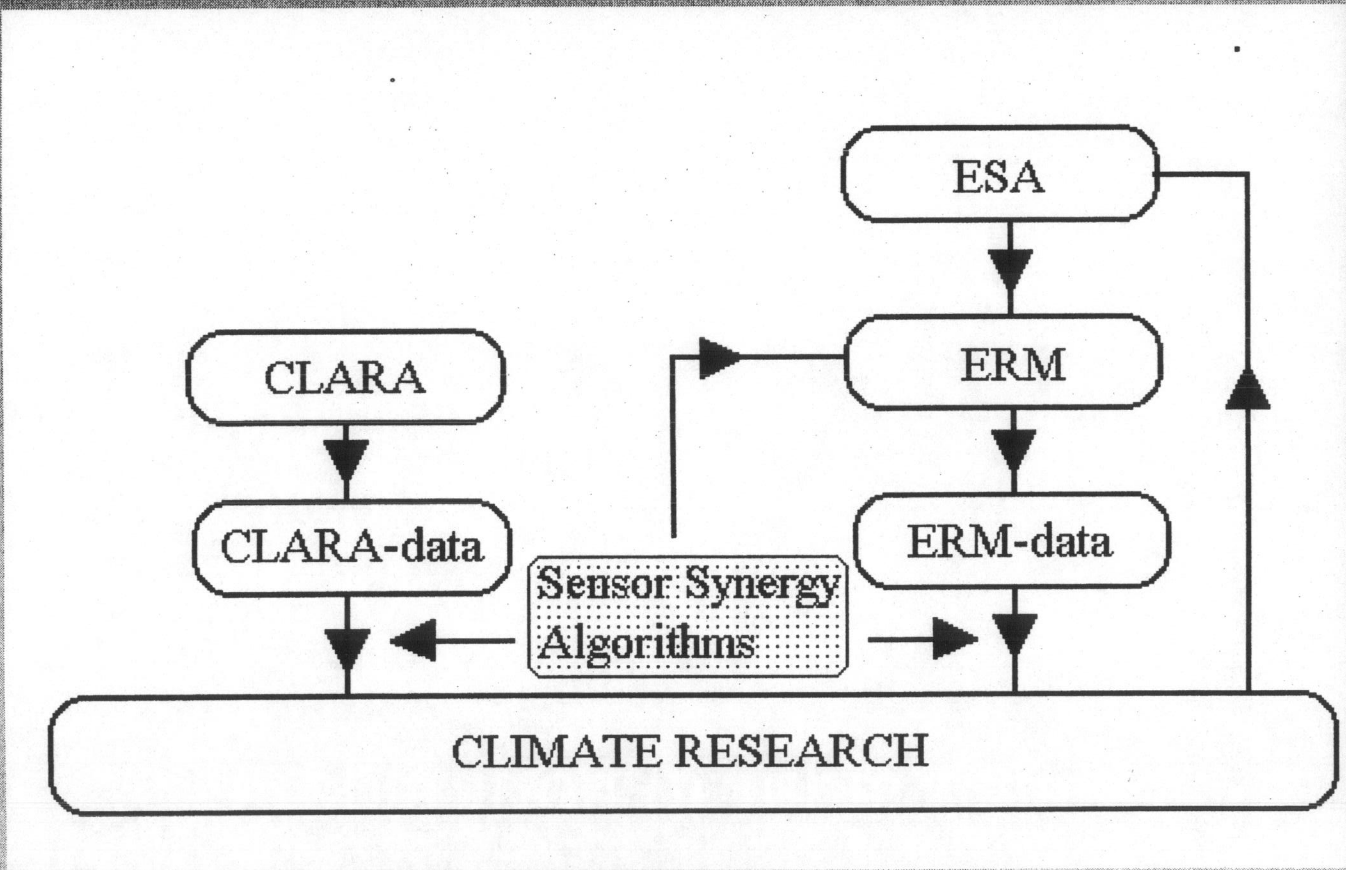
CLARA-campaigns in 1996

	Period	Nr. of Flights
CLARA-I	15 - 30 April	3
CLARA-II	19 Aug.t - 4 Sept.	7
CLARA-III	18 Nov. - 7 Dec.	6

Total of 43 flight hours

KNMI

Research Strategy



Koninklijk Nederlands Meteorologisch Instituut

Preparation of input data set

- Review of ERM
- Review of CLARA data set
  - Radar, Lidar, aircraft, satellite
- Cases are selected
- Study Note: "Description of selected CLARA data sets for the support of ERM"
- 2 months

KNMI

Study for selected cloud scenarios

- Derive macroscopic cloud properties from individual instruments
- Derive macroscopic cloud properties from combined instruments and possibilities to derive microscopic properties
- study note: "Description of selected CLARA data sets for the support of ERM"
- 4 months

KNMI

Koninklijk Nederlands Meteorologisch Instituut

Study of cloud variability

- Study of cloud variability on basis of single instrument observations
- Study of cloud variability on basis of temporal/spatial separation
- Study note: "Study of cloud variability"
- 4 months

KNMI

Project Team

Project leader
Dr. A van Lammeren

Contract managager
Ms. I. de Wit

Advisors:
- Dr. H. Russchenberg (IRCTR/TUD)
  Radar specialist
- Mr. A. Apituley (RIVM)
  Lidar specialist
- Mr. A. Feijt (KNMI)
  Passive satellite RS specialist

Project scientists:
- Dr. D. Donovan (KNMI)
- Dr. H. Bloemink (KNMI)

KNMI

Recent results

- Some examples of the selected cases will be shown

KNMI

Concluding remarks

- Combination with other projects
- Work is done in cooperation with H. Russchenberg (IRCTR/TUD) and A. Apituley (RIVM)
- Goal is to optimize sensor synergy for the ERM

I. THE UNDERLYING SCIENCE

STUDY ON CRITICAL REQUIREMENTS FOR A CLOUD PROFILING RADAR

E. RASCHKE, GKSS

GKSS FORSCHUNGSZENTRUM

esa

MPB

Study on Critical Requirements for a Cloud Profiling Radar

(ESTEC Contract 11327/94/NL/CN)
- ESA CR(P)-4108 -

"Radiation Day", 1 September 1998

GKSS, Geesthacht
Ehrhard Raschke
Henriette Lemke
Markus Quante
Olaf Danne

MPBT, Montreal
Ralph Girard
Peter Park

Purpose of the study

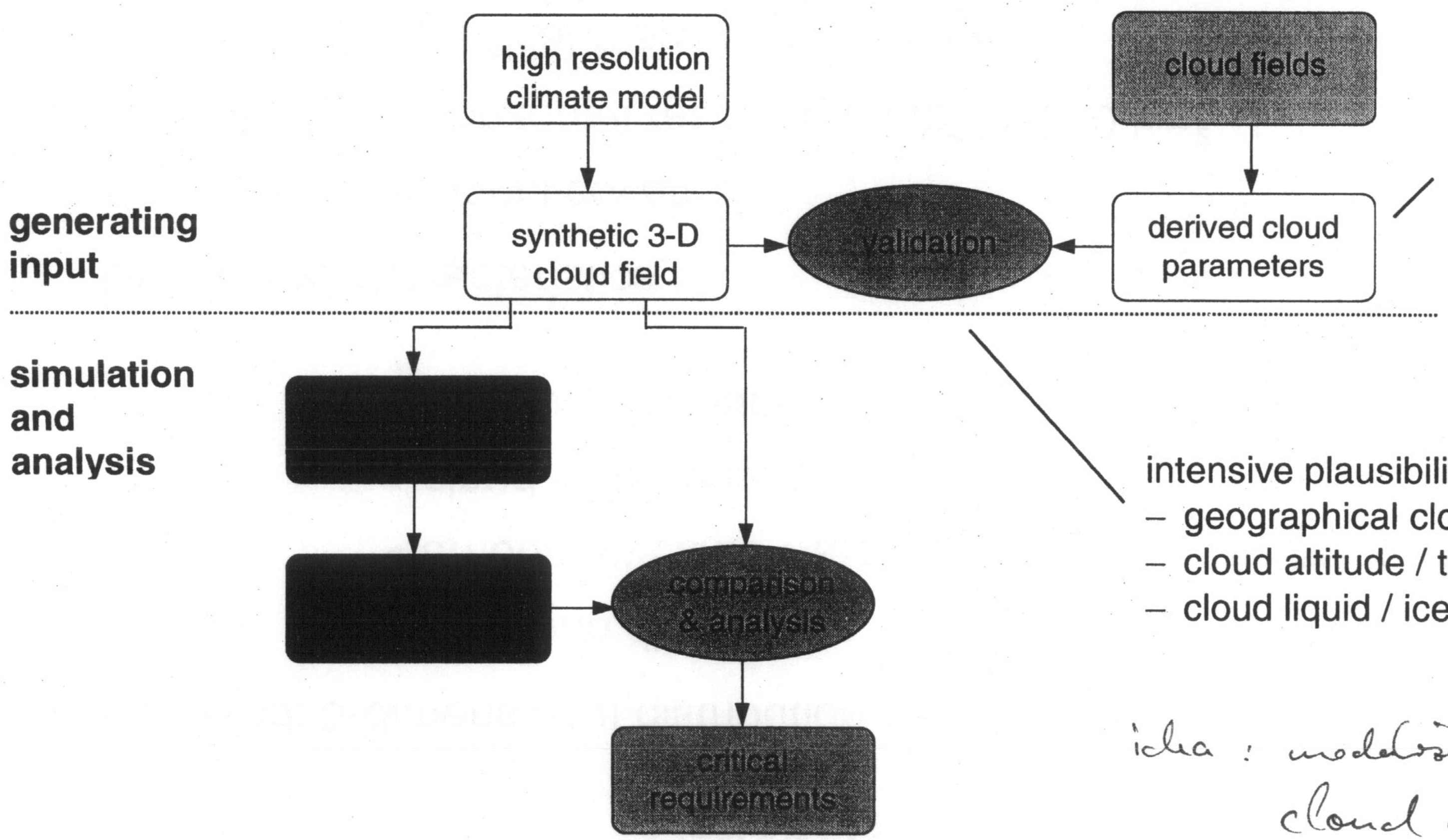
GKSS FORSCHUNGSZENTRUM

- Assess the capability of a space-borne cloud profiling radar to retrieve cloud boundaries (incl. number of layers) on a global scale.

- Estimate scientific (technical) requirements for a cloud radar mission, esp. for
  - radar sensitivity (reflectivity threshold);
  - sampling in space and time.

Overall Approach of the Study

GKSS FORSCHUNGSZENTRUM



data available from
- passive satellite instrum.
- ground-based observ.
- aircraft measurements

intensive plausibility check:
- geographical cloud distribution
- cloud altitude / thickness
- cloud liquid / ice water content

idea : modelisation of a global cloud model
simulation of analysis

Rationale

GKSS FORSCHUNGSZENTRUM

Required: 3-dimensional distribution of

- 3D cloud distribution
- amount of cloud water
- cloud water phase
- absolute humidity

Demanded characteristics

- global coverage
- horizontal resolution $\leq 250 \times 250\ km^2$
- vertical resolution ≤ 500 m
- time steps: capture roughly the daily cycle
- period: full month

$\Rightarrow$ is not yet available from observations nor can be interpolated in a realistic manner (consistently) from available observations!

Data Source: ECHAM4 Climate Model

- Forced by measured SST and observed sea ice limits.
- Conserving the total water mass (all phases).
- High resolution run (T106) for the period 1977-1986.

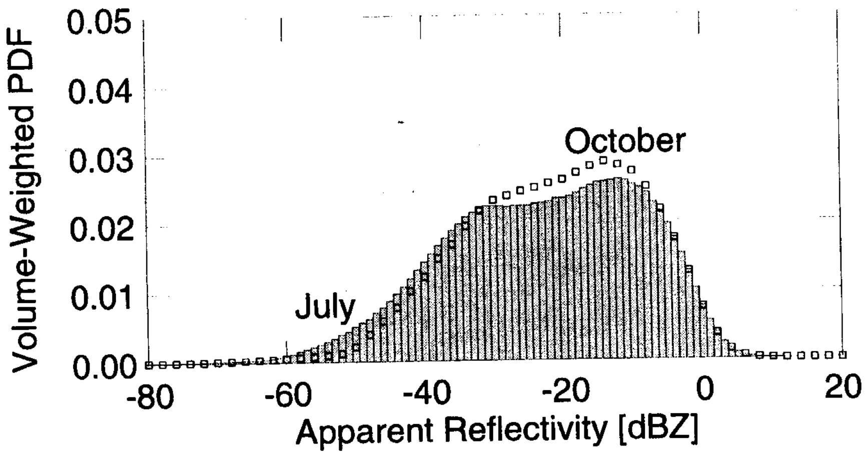
meridional resol.:	≈1.125° (Gaussian grid)
zonal resolution:	1.125° (equidistant grid)
vertical resolution:	19 uneven layers (<300m to ≈2km)
time resolution:	6 h
selected period:	1 summer month, 1 autumn month (July 1985, October 1985)

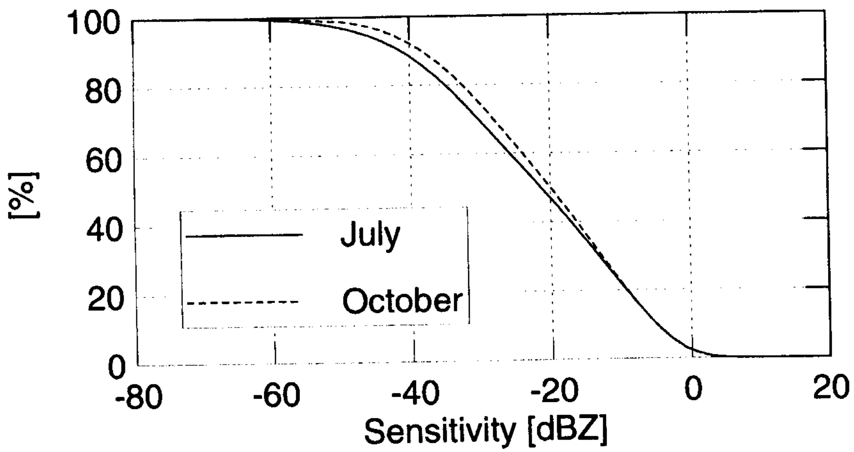
- Prognostic variables of the ECHAM4 model are:

– vorticity	– surface pressure
– divergence	– water vapour
– temperature	- cloud water *(!)*

Threshold Effect: Ideal Sampling

Apparent (Attenuated) Reflectivity
(max. overlap)



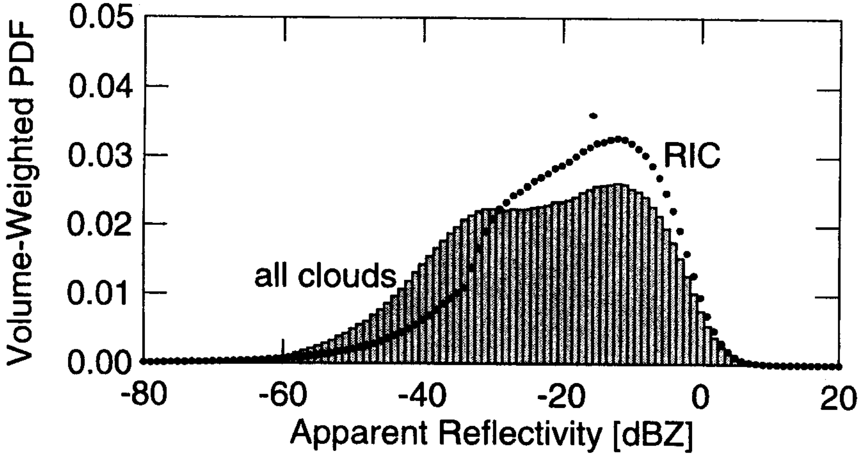


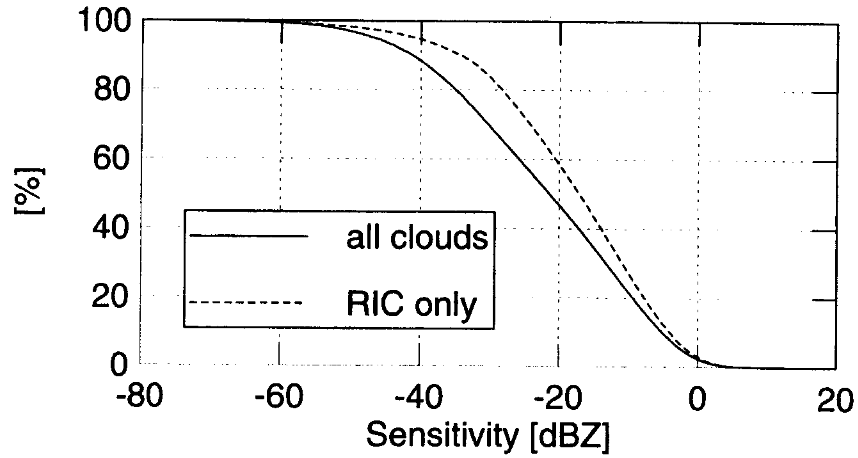
Cloud volume fraction exceeding a given apparent reflectivity:

reflectivity	July	October
-20 dBZ	47%	50%
-30 dBZ	69%	75%
-40 dBZ	88%	92%

Radiatively Important Clouds (RIC)

Apparent Reflectivity





RIC identification depends on short wave optical thickness and area of cloud cover:

1. $\delta_{SW} > 0.05$

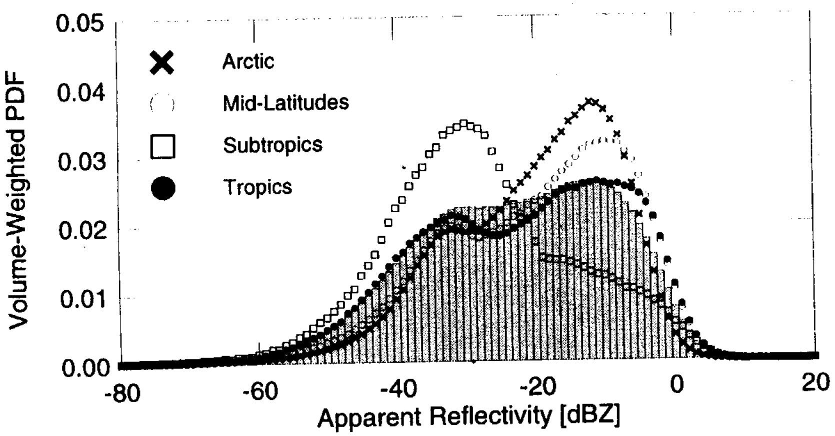
2. cloud cover $b > b_{crit}$

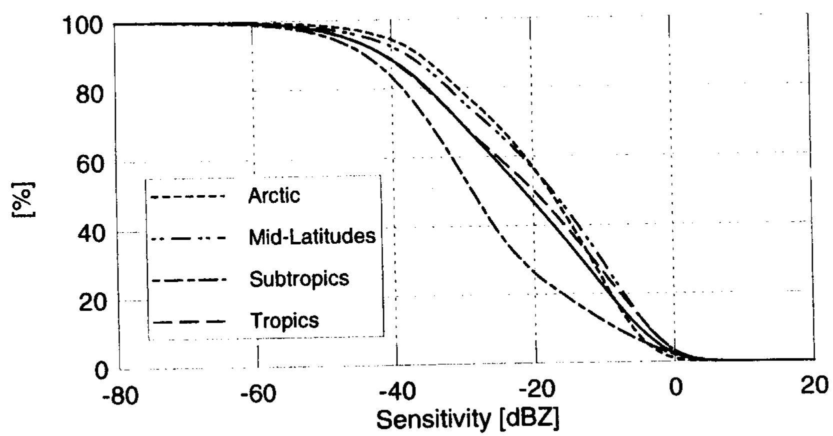
Detectable cloud volume fraction:

threshold	July all	July RIC	October all	October RIC
-20 dBZ	47%	59%	50%	60%
-30 dBZ	69%	84%	75%	86%
-40 dBZ	88%	95%	92%	95%

Latitude bands

Apparent Reflectivity





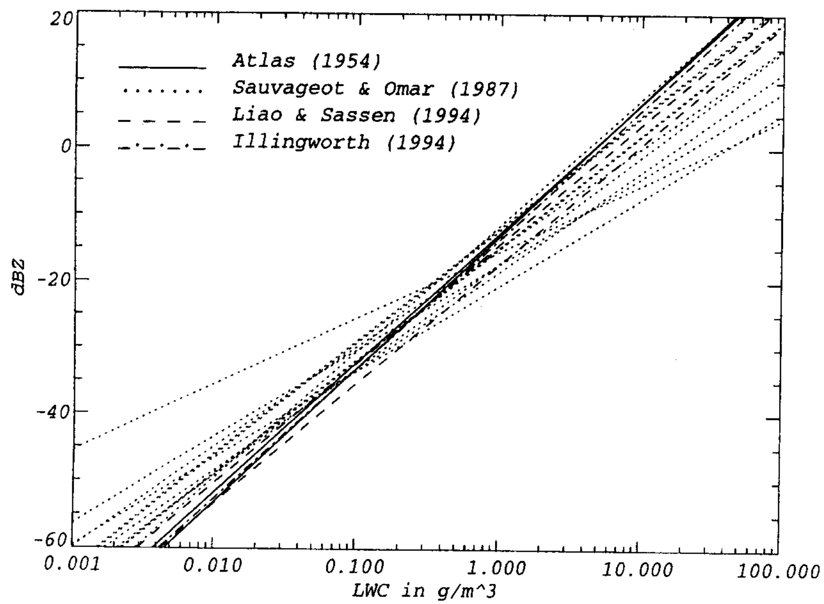
Region	Latitude
Tropics	0° - 15° N
subtropical Ocean	15° S - 30° S
Northern Mid-Lat.	30° N - 60° N
Arctic	60° N - 90° N

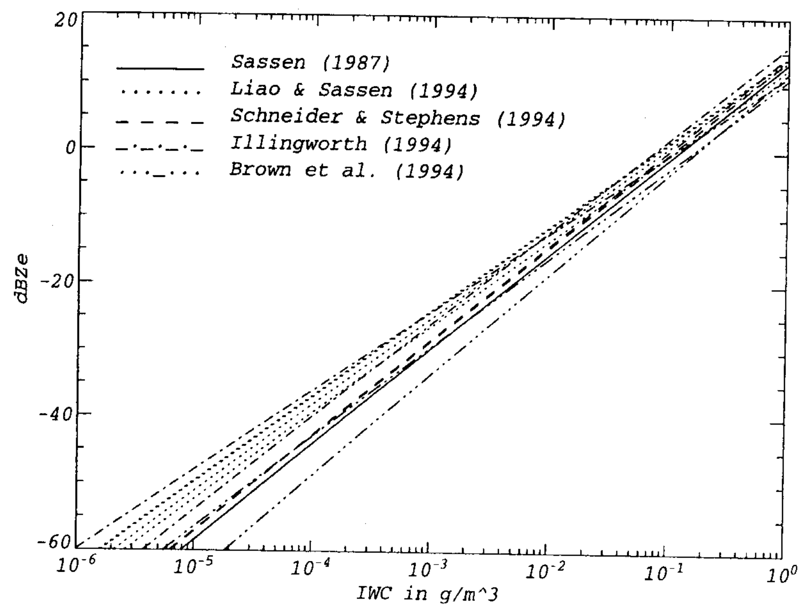
detectable cloud volume fraction:

thresh.	Arctic	Mid-Lat.	Subtrop.	Tropics
-20 dBZ	57 %	56 %	26 %	50 %
-30 dBZ	79 %	76 %	55 %	69 %
-40 dBZ	94 %	92 %	83 %	88 %

Uncertainty in the CWC-Z relation

Relationship between cloud liquid / ice water content and radar reflectivity:

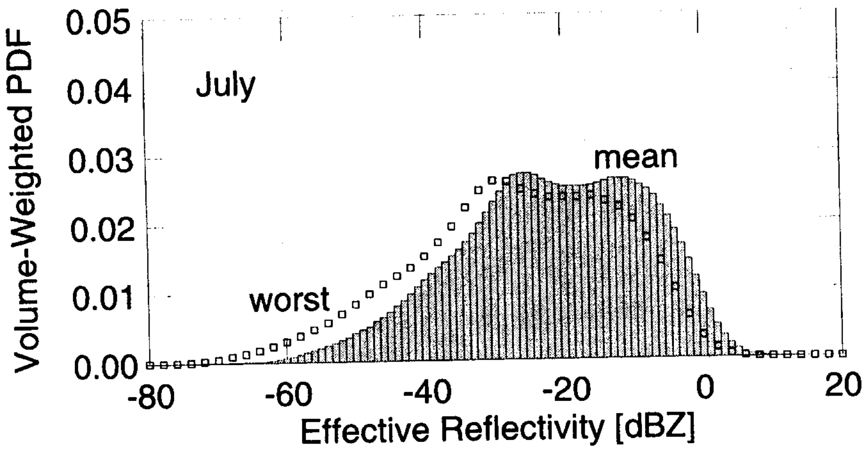


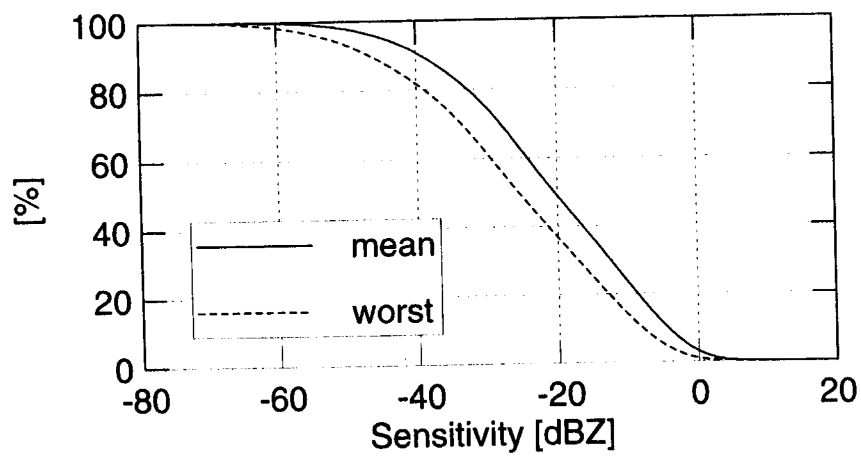


⇒ A mean of lots of existing Z-LWC/IWC relations was regarded as most justified.

Effect of uncertainty in the CWC-Z relation

Effective Reflectivity
(July, global)





cloud volume fraction exceeding a certain sensitivity threshold

threshold	July		October	
	Δ_{abs}	Δ_{dBZ}	Δ_{abs}	Δ_{dBZ}
-20 dBZ	12%	5 dBZ	13%	5 dBZ
-30 dBZ	13%	6 dBZ	13%	6 dBZ
-40 dBZ	9%	7 dBZ	8%	7 dBZ

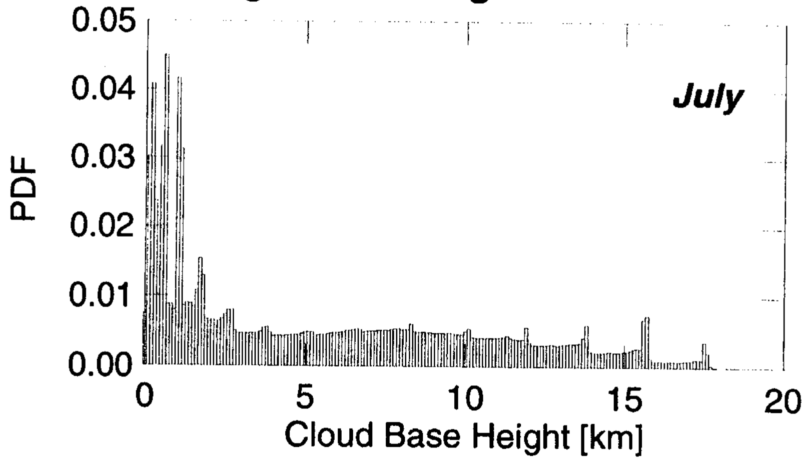
Problem of Blind Layer

For a space-borne CPR, the 1st range gate above ground will be inaccessible because of ground clutter.

Distribution of cloud base height

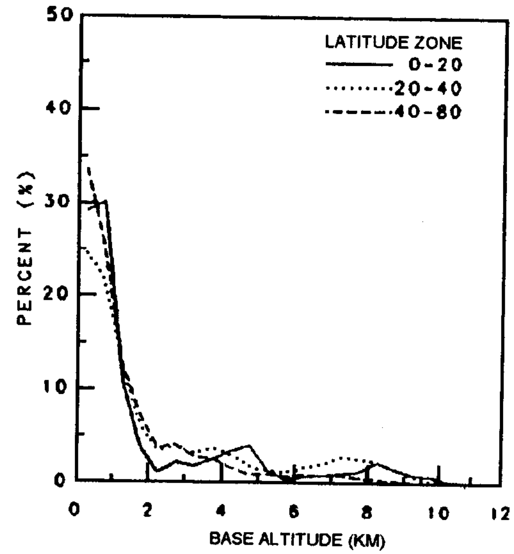
Generated Data Sets

grid-average cloud base height above ground level



≈10% of all cloud bases below 500 m

Observational Data



rawin sonde data (global) collected by Poore et al. (1995)

Sampling Effect

GKSS FORSCHUNGSZENTRUM

Orbit parameters used for simulations

	orbit #1	orbit #2
repeat cycle	14 days	22 days
altitude	583 km	603 km
orbit	sun synchronous	
frequency	94 GHz	
range resolution	500 m	
footprint size	1 km	
integration length	10 km	

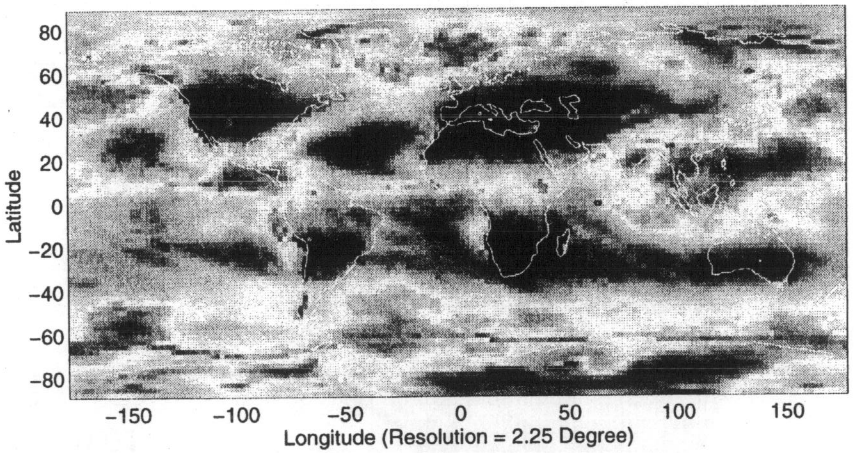
No threshold !!

Main question: *Is the sampled subset a satisfying representation of the input data set?*

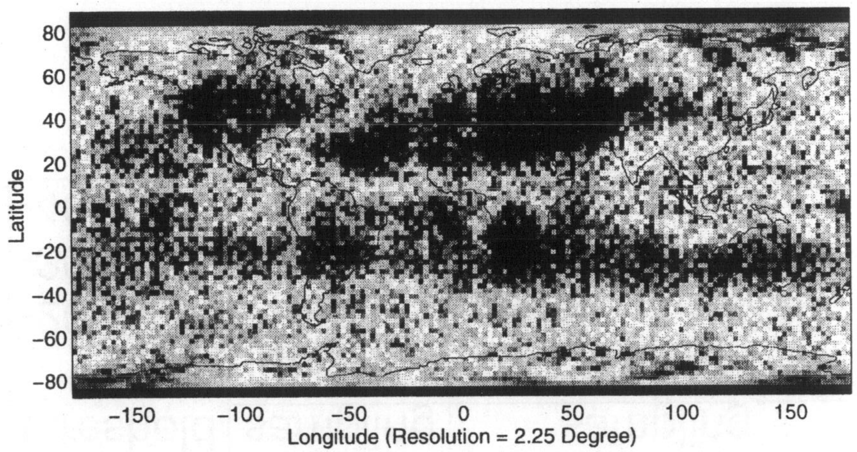
Monthly Mean Fractional Cloud Cover

Simulated space-borne cloud radar observations for various thresholds
(July, orbit #1)

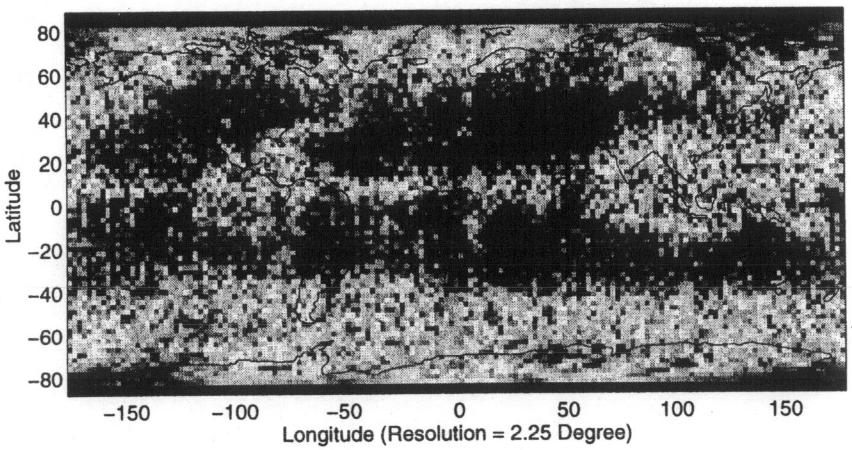
Input data set (mean=47%)



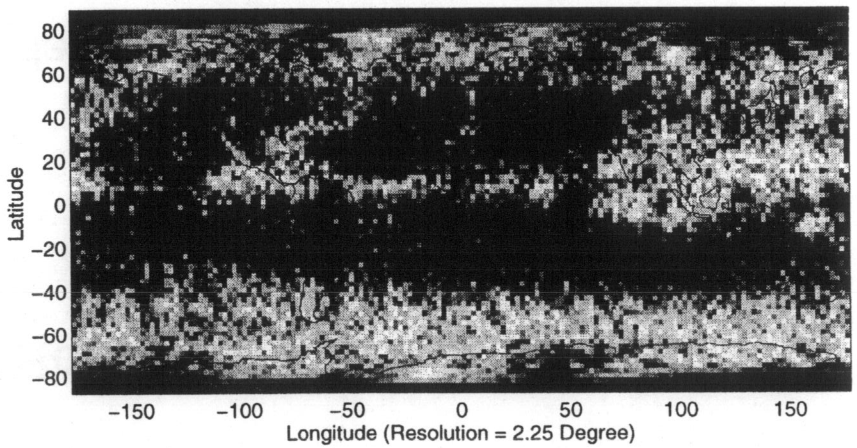
-40 dBZ threshold (mean= 39%)

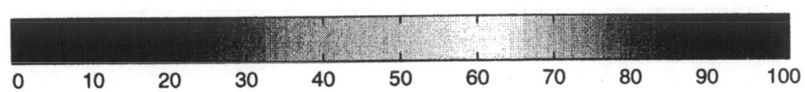


-30 dBZ threshold (mean=33%)

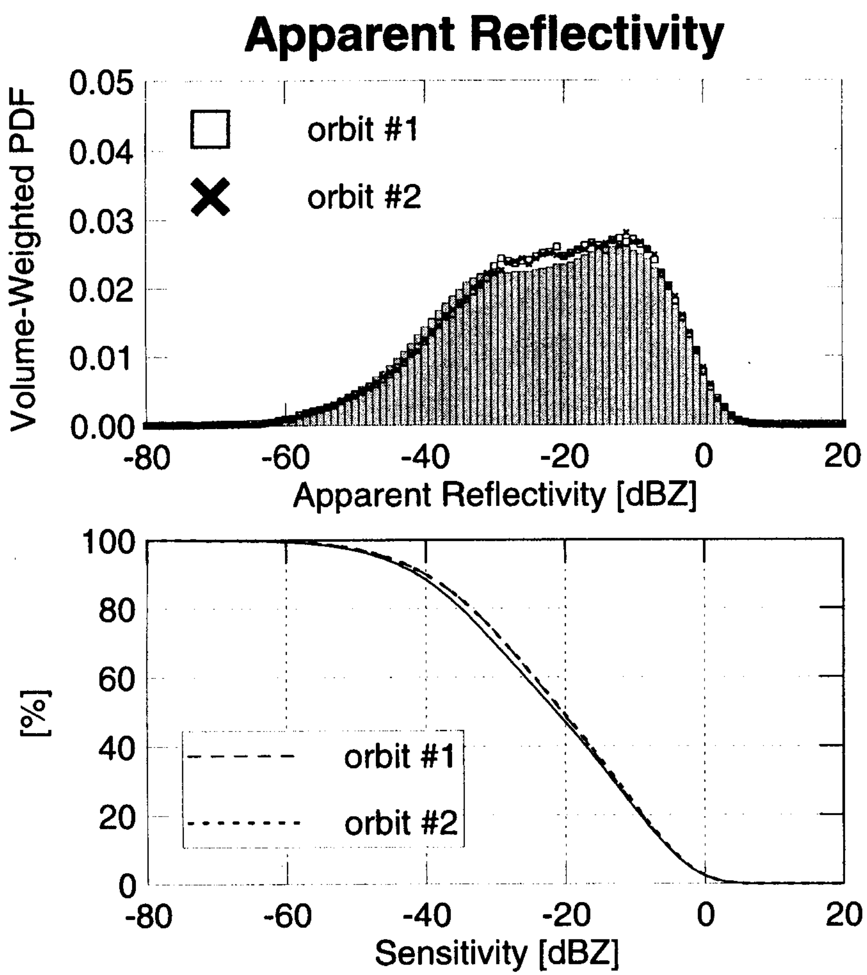


-20 dBZ threshold (mean= 22%)





Sampled & Input Apparent Reflectivity



detected cloud volume fraction:

threshold	ideal sampling	realistic sampling	
	input	orbit #1	orbit #2
-20 dBZ	47%	49%	49%
-30 dBZ	69%	73%	73%
-40 dBZ	88%	90%	90%

Conclusions

GKSS FORSCHUNGSZENTRUM

- Presently, no satellite data product resolves the vertical cloud distribution with sufficient resolution to derive fluxes within the atmosphere and at the surface with the desired accuracy.

  ⇒ To include a cloud radar as a high priority candidate into the list of potential elements for an ERM is strongly recommended.

- Sensitivity limit better than -30 dBZ would be desirable from the scientific point of view. However, for any threshold between -30 and -40 dBZ, the obtained 3D cloud distribution would be more comprehensive and more valuable than those presently available.

- In the given height range, different polar orbits would provide similar cloud radar results, hence it is recommended that an optimised orbit should be selected on the basis of a synergy study for the total mission. Small angle scanning would not improve the ability to sample a representative subset of data.

I. THE UNDERLYING SCIENCE

STUDY OF THE CRITICAL REQUIREMENTS FOR A CLOUD RADAR

A. ILLINGWORTH, UNIVERSITY OF READING

STUDY OF THE CRITICAL REQUIREMENTS

FOR A CLOUD RADAR

by

Anthony Illingworth, ChunLei Liu, and Robin Hogan

JCMM, Department of Meteorology

University of Reading

Reading, UK RG6 6BB, UK

1 September 1998

EOPP Seminar on Radiation Studies

ESTEC

1.

STUDY ON THE CRITICAL REQUIREMENTS OF A CLOUD RADAR

11326/95/NL/CN FINAL PRESENTATION DEC 96

OVERVIEW

CLOUDS ARE A CRITICAL ELEMENT IN THE EARTH'S RADIATION BUDGET

LOW CLOUDS REFLECT VISIBLE SOLAR RADIATION -

COOL THE CLIMATE BY ABOUT -30 W m^{-2}

HIGH CLOUDS ARE COLD AND RADIATE LESS IN THE INFRA RED

BACK TO SPACE - WARM THE CLIMATE BY +30 W m^{-2}M.

NET EFFECT OF CLOUDS IS A COOLING OF ABOUT -20 W m^{-2}

(DIRECT FORCING OF DOUBLED CO_2 WARMING OF +4 W m^{-2}.

GLOBAL VERTICAL PROFILE OF CLOUDS CRUCIAL

SATELLITE RADIOMETERS SEE THE TOPS OF CLOUDS
- GROUND BASED CLOUD BOTTOM.

NEED AN ACTIVE RADAR TO MEASURE CLOUD VERTICAL PROFILE

CLOUDS ARE WEAK RADAR TARGETS (50dB < LIGHT RAIN)

USE HIGH FREQUENCY RADAR TO GET MORE RETURN SIGNAL

94/78 GHz RADAR - LOW EARTH ORBIT - 2m ANTENNA - 1Km FOOTPRINT

ATTENUATION BY WATER VAPOUR AND CLOUDS THEMSELVES

QUESTION (JCMM) - WHAT SENSITIVITY TO DETECT ALL RADIATIVELY IMPORTANT CLOUDS?

QUESTION (ESSC) - 1Km SWATH, LOW EARTH ORBIT - VISITS 250Km BOX - ONCE A DAY - IS THIS A REPRESENTATIVE SAMPLE OF CLOUDS?

QUESTION (MMS) - HARDWARE DESIGN TO MAXIMISE SENSITIVITY?

EARLY STUDIES: SUGGEST -30dBZ SENSITIVITY FOR

1 SECOND (7Km) INTEGRATION TIME

500m VERTICAL RESOLUTION

4. STUDY ON THE CRITICAL REQUIREMENTS OF A CLOUD RADAR

11326/95/NL/CN FINAL PRESENTATION DEC 95

SENSITIVITY REQUIREMENTS REVIEW

CONSIDER CLOUDS ARE SIGNIFICANT IF THEY LEAD TO OLR FLUX CHANGES OF 5 W/m^2 AT SURFACE OR TOA (TOP OF THE ATMOSPHERE).
- THIS IS ACCURACY OF SATELLITE OBSERVATION.

DISCUSS DETECTABILITY OF CLOUDS IN TERMS OF RADAR SPECIFICATION:

-30dBZ	500M LONG GATE
1Km FOOTPRINT	ALONG TRACK INTEGRATION?

RADAR REFLECTIVITY OF CLOUDS:

$Z = \Sigma N D^6$ (N is concentration, D is diameter),

LIQUID WATER CLOUDS SUCH AS STRATOCUMULUS - WIDESPREAD OVER THE COLD OCEANS, VERY IMPORTANT RADIATIVELY (COOL THE CLIMATE).

ICE WATER CLOUDS, SUCH AS CIRRUS - WIDESPREAD FROM TROPICAL ANVILS, IMPORTANT RADIATIVELY (WARM THE CLIMATE).

OPTICAL DEPTH, WATER CLOUD: $\tau = 3\ LWP / 2\ r_e$
{ LWP, liquid water path in g m^{-2}; r_e effective radius in microns)

ICE CLOUD: $\tau = 3\ IWP / 4\ \rho_I\ r_e$
{ IWP is ice water path, ρ_I is density of ice}

Direct radiation flux through cloud falls as:

$$I = I_o \exp(-\tau)$$

{down by 63% for an optical depth of 1, by 1% for a tau of 0.01}.

STRATO CUMULUS CLOUDS: r_e about 10um.
CIRRUS CLOUDS: r_e about 100um.

So for same water content Z of cirrus is 1000 times higher
τ of cirrus is 10 times lower.

Radiatively significant ice clouds much easier to detect with radar than radiatively significant stratocumulus clouds.

MIXED PHASE CLOUDS - CO-EXIST IN GRID BOX OF 60-70KM;
OCCUR RARELY ON 1KM SCALE OF RADAR FOOTPRINT - 100km INTEGRATION?

5. **WHAT IS A RADIANTLY SIGNIFICANT CLOUD?**

RADIATIVELY SIGNIFICANT ICE CLOUDS -

CHANGE OUTGOING LONG WAVE RADIATION AT THE TOP OF THE ATMOSPHERE BY 5 OR 10W m^{-2}

- EQUIVALENT TO A τ OF 0.04 OR 0.07 IF r_e 20μm

AN IWP OF 1 g m^{-2} - 1KM DEEP CLOUD, IWC 0.001 g m^{-3}

RADIATIVELY SIGNIFICANT WATER CLOUDS? -

LWP OF 1 g m^{-2} CHANGES EMISSIVITY and ALBEDO.

- ADIABATIC CLOUDS ONLY 50m DEEP HAS THIS LWP.

BUT BEST CURRENT METHOD FOR LWP FROM SPACE IS SSM/I

IN CLEAR SKY STANDARD DEVIATION OF LWP IS 16 g m^{-2}

WITH TYPICAL ERROR 20 g m^{-2}

DATA SOURCES

RADAR AND RADIATION PROPERTIES OF CLOUDS PREDICTED FROM AIRCRAFT MEASUREMENTS OF SHAPE AND SIZE OF CLOUD PARTICLES

PROBES

FSSP - WATER DROPLETS DIAMETER 2 - 47μm - FIFTEEN 3μm BINS

2D-C IMAGING PROBE DIAMETERS 25 - 800μm - THIRTY TWO BINS.

WATER CLOUDS - STRATOCUMULUS

OVER 4000KM OF PENETRATIONS

70 STRAIGHT LEVEL PENETRATIONS

MADE AROUND THE UK AND S. NORTH ATLANTIC

ICE CLOUDS - CIRRUS

EUCREX - NORTH SEA - 7,900 5-SEC SPECTRA - 5,100KM

CEPEX - TROPICAL - 11,700 10-SEC SPECTRA - 22,800KM

REFLECTIVITIES QUOTED RELATIVE TO THE RETURN FROM A SINGLE WATER DROPLET ONE MM DIAMETER PER CUBIC METER.

LIQUID WATER CLOUDS

MEASUREMENT OF DROPLET SPECTRA OF STRATOCUMULUS SHOW:

REFLECTIVITY AS A FUNCTION OF LIQUID WATER CONTENT

$$Z = 0.031\ LWC^{1.56}$$

Z IN $MM^6\ M^{-3}$; LWC IN $G\ M^{-3}$

IF WE CONSIDER CLOUD DROPLETS ONLY.

ADIABATIC CLOUDS:

	DEEP	AV LWC ($G\ M^{-3}$)	LWP ($G\ M^{-2}$)	Z(cloud)
	50m	0.025	1	-40dBZ
	150m	0.075	10	-32.5dBZ
	200m	0.1	20	-30.6dBZ
(50% ADIABATIC)	200m	0.05	10	-35dBZ

NOW SSM/I SENSITIVITY/ERROR IS 20 $G\ M^{-2}$

SO WE WILL CONSIDER LWP OF 1 AND 10 $G\ M^{-2}$.

WE WILL FIND THAT IN MANY MARINE STRATOCUMULUS THE PRESENCE OF OCCASIONAL DRIZZLE SIZED DROPLETS RAISES THE REFLECTIVITY

e.g. ONE 200μm DROPLET PER LITRE HAS A Z OF -12dBZ
BUT A LWC OF ONLY 0.04 $G\ M^{-3}$

THE OCCASIONAL DRIZZLE DROP HAS NEGLIGIBLE LWC AND PPN BUT INCREASES Z.

OCCASIONAL DRIZZLE DROPLETS ARE PREVALENT IN EXTENSIVE

'MARINE' STRATOCUMULUS DEEPER THAN ABOUT 150m.

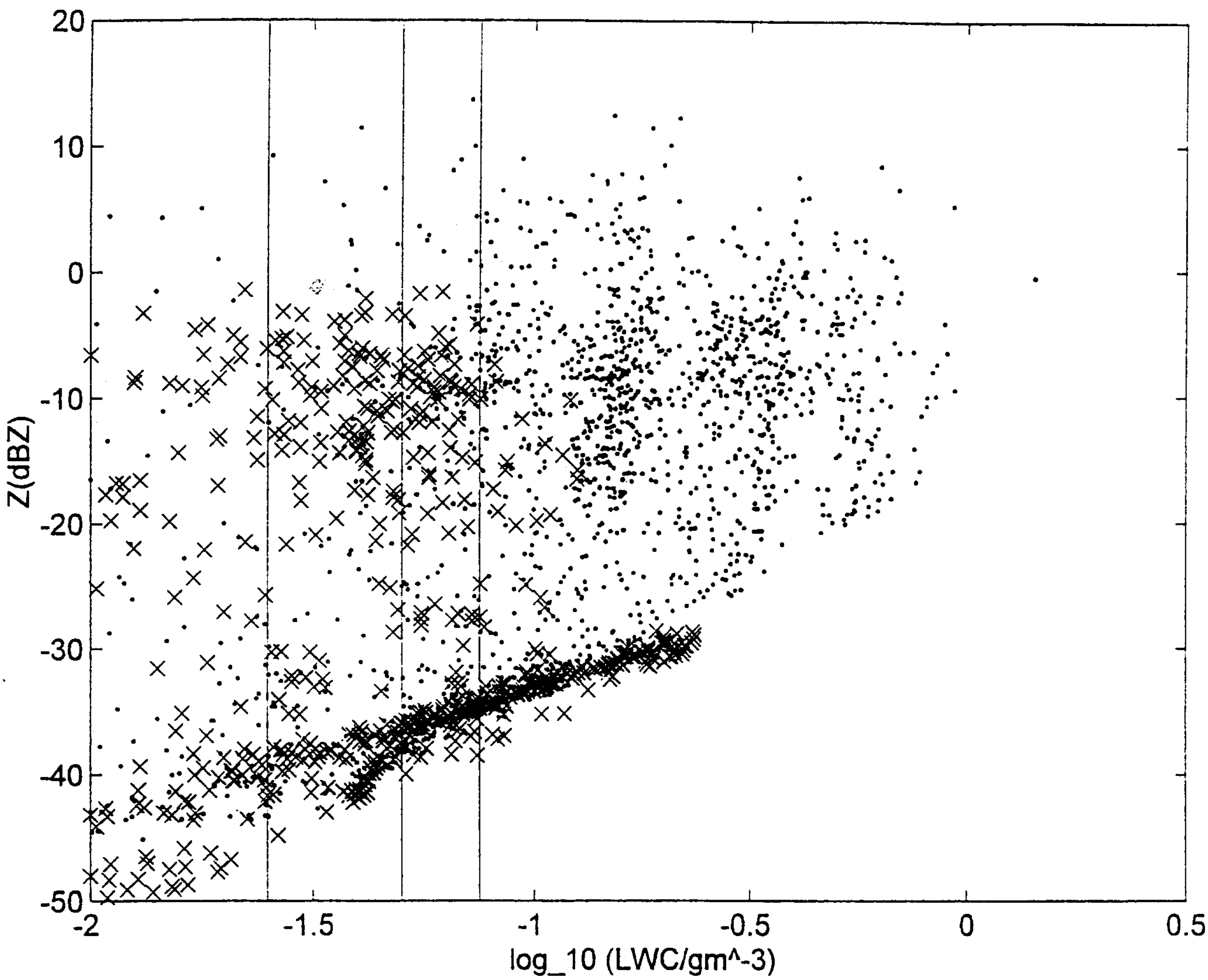
'MARINE' IS THE AIRMASS - ONLY A FEW CONDENSATION NUCLEI.

IN 'CONTINENTAL' AIRMASSES - LESS DRIZZLE.

GLOBALLY IMPORTANT STRATOCUMULUS ARE 'MARINE'.

8.

Figure 3.3.6: Scattergram of calculated Z against LWC for all maritime (.) and continental (x) Sc samples with Z>-50dBZ. The three vertical lines correspond to liquid water contents of 0.025, 0.05 and 0.075gm^{-3}.



STRATOCUMULUS - CONCLUSIONS FROM AIRCRAFT CLOUD SIZE SPECTRA

1) DRIZZLE SIZED PARTICLES ARE PREVALENT IN MARINE STRATOCUMULUS, (ABSENT IF THINNER THAN 200m) - SOMETIMES FOUND IN CONTINENTAL.

2) THESE OCCASIONAL DRIZZLE PARTICLES - ALTHOUGH INSIGNIFICANT IN TERMS OF LIQUID WATER CONTENT AND RADIATIVE PROPERTIES - RAISE THE RADAR REFLECTIVITY OF THE CLOUD. (SO LWC NOT f(Z))

3) DRIZZLE SIZED DROPLETS PRESENT THROUGHOUT THE CLOUD AND APPEAR TO BE BOUNDED ONLY BY CLOUD EDGE.

USUALLY EVAPORATE WITHIN 200m OF CLOUD BASE.

4) CONSIDERING A SIGNIFICANT CLOUD TO HAVE LWP OF 10 g m^{-2}

THIS COULD BE 150M DEEP AND HAVE AN LWC OF 0.075g m^{-3}

OR 200m DEEP AND AN LWC OF 0.05 G m^{-3}

MARINE AIRMASS - PERCENTAGE DETECTION:

	LWC 0.05	0.075
z >-40dBZ	100	100
>-35dBZ	95	99
>-30dBZ	85	90

CONTINENTAL AIRMASS - PERCENTAGE DETECTION:

	LWC 0.05	0.075
z >-40dBZ	100	100
>-35dBZ	82	97
>-30dBZ	33	25

FOR 0.1GM^{-3} THEN -35dBZ WILL DETECT 100% FOR BOTH.

5) AVERAGING STRATOCUMULUS REFLECTIVITY OVER DISTANCES OF 7KM RATHER THAN 1km DOES NOT APPEAR TO BIAS THE MEASURED Z.

6) ATTENUATION OF RADAR SIGNAL NEGLIGIBLE FOR LIQUID WATER PATH 10 G M^{-2}, DEEPER CLOUDS DRIZZLE DROPLETS RAISE Z CONSIDERABLY.

11.

ICE CLOUDS - CIRRUS

SIZE SPECTRA CLOSE TO EXPONENTIAL:

$$N(D) = N_{\circ} \ EXP \ (-D/D^{*}) = N_{\circ} \ EXP \ (-3.67 \ D/D_{\circ})n$$

SO THAT IWC AGREE WITH TOTAL IWC EVAPORATIVE INSTRUMENT

ICE DENSITY A FUNCTION OF PARTICLE SIZE

$$\rho_{ICE} = 0.07 \ D^{-1.1}$$

i.e. SMALL ICE PARTICLES SOLID, LARGER ONES LOWER DENSITY.

BECAUSE Z PROPORTIONAL TO D^6 AND IWC TO D^3

THEN FOR A GIVEN IWC Z LARGER AS D* INCREASES.

THIS GIVES SCATTER SO THAT DERIVING IWC AS A FUNCTION OF Z

HAS A STANDARD DEVIATION OF +100%/-50%

BROWN ET AL SUGGEST THAT IF Z AND D* ARE KNOWN

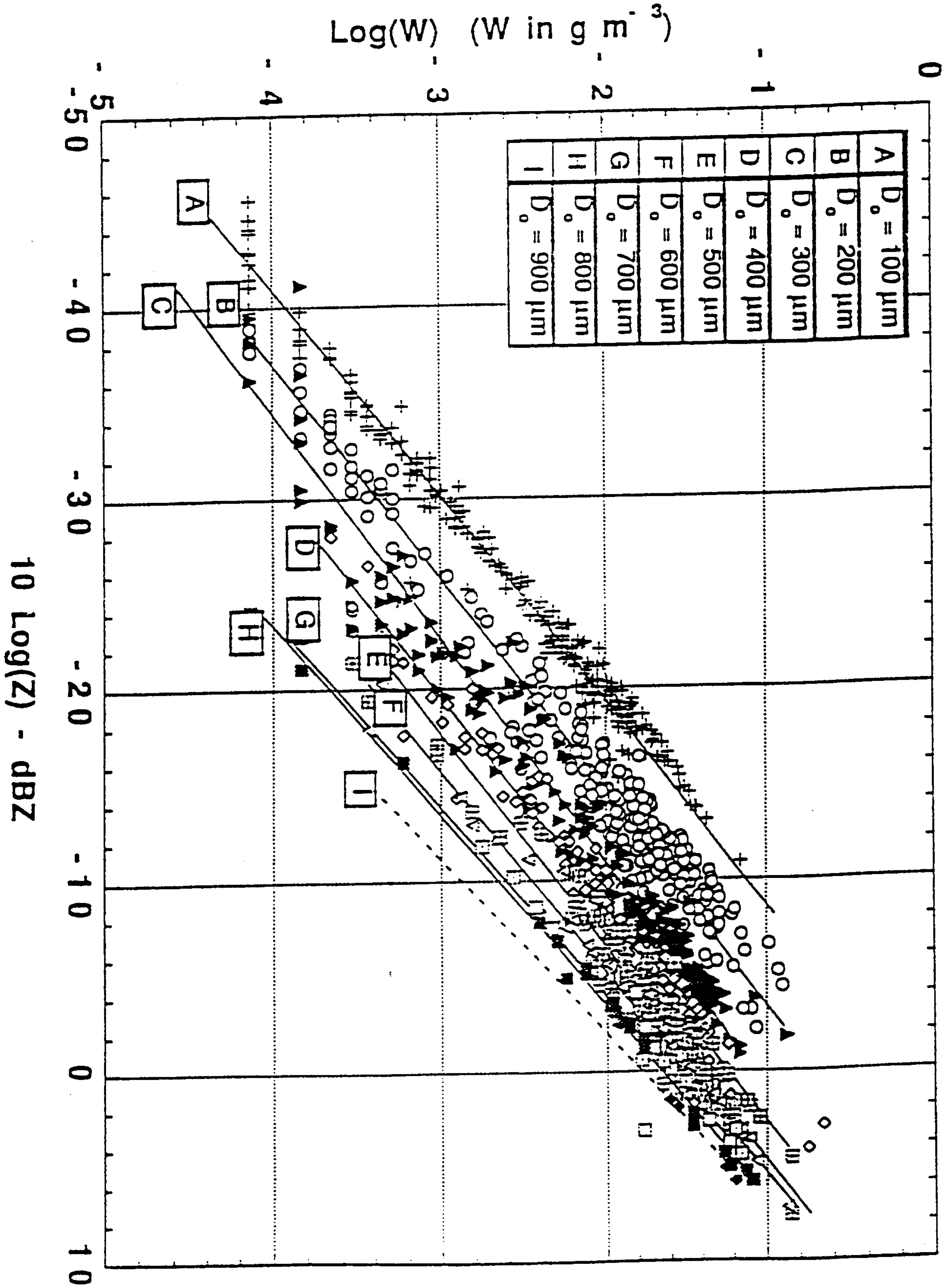
STANDARD DEVIATION REDUCED TO +50% AND -35%.

ALSO THE FIT OF IWC VERSUS Z VARIES FROM DAY TO DAY.

- SEE NEXT TWO SLIDES.

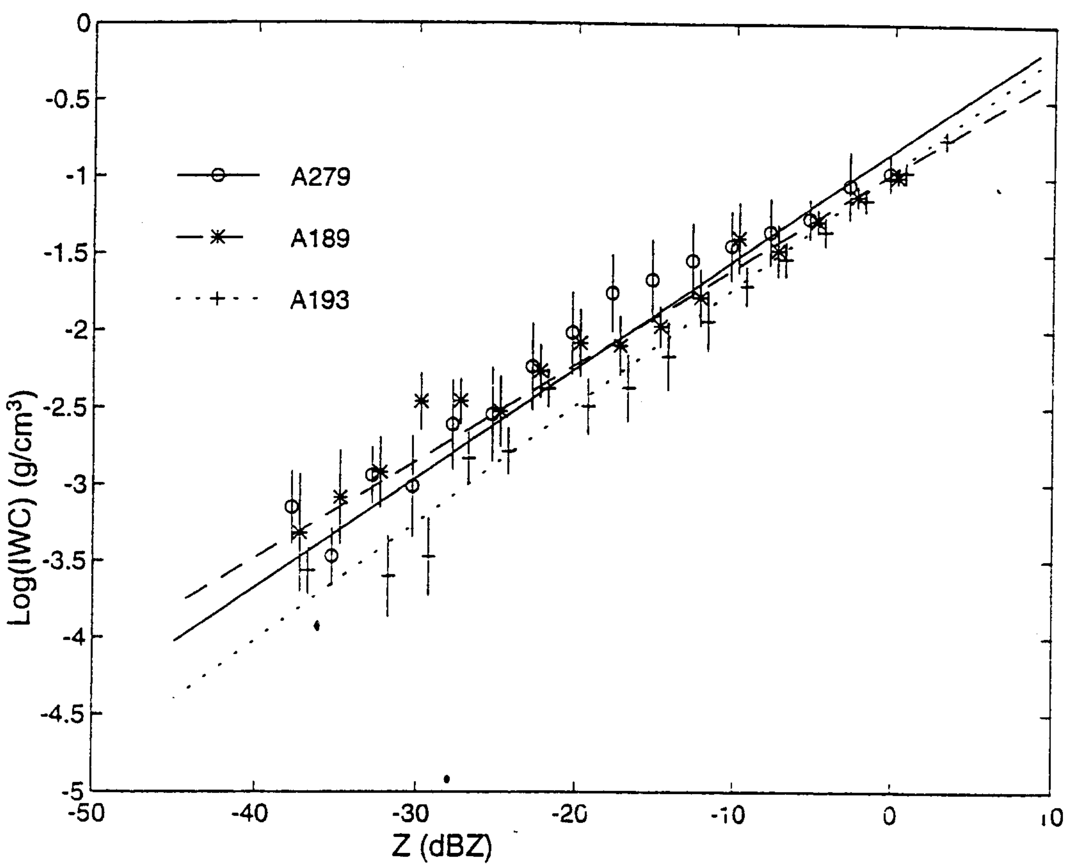
12.

Figure 3.4.1. Scatter plot of IWC and Z values from Atlas et al (1995).



\13,

Figure 3.4.3. IWC-Z relations and the standard deviation for three days of EUCREX data.



14.

RADIATIVELY SIGNIFICANT ICE CLOUD.

FOR AN INVERSE-EXPONENTIAL SIZE DISTRIBUTION,

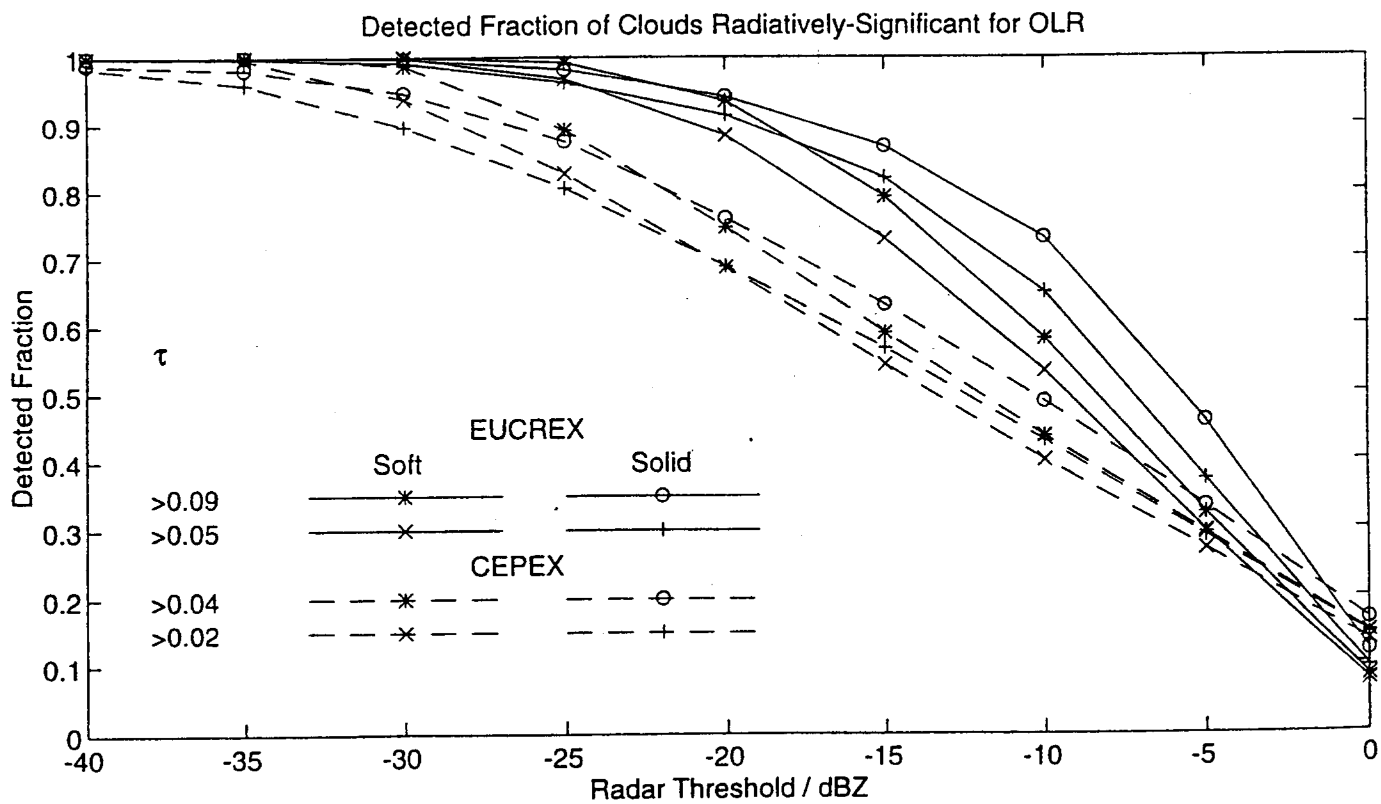
THE EFFECTIVE RADIUS R_e = 1.5D*

ASSUME CLOUD 1KM (1000m) THICK

SO OPTICAL DEPTH, τ = (3 1000 IWC/ 4 1.5 D*)

GRAPH COMPARES 5 AND 10 W M^{-2} THRESHOLD

Figure 3.4.4 Detected cirrus cloud fraction variation with the radar threshold for solid (ρ=0.9gcm^{-3}) and soft (ρ=0.07D$^{-1.1}$) ice crystals, respectively.



15.

SIZE DERIVED FROM LIDAR/BACKSCATTER RATIO

INTRIERI ET AL (1993) ESTIMATED PARTICLE SIZE FROM THIS RATIO:

ASSUMING ICE PARTICLES ARE SPHERICAL AND SOLID,

USING 35GHz RADAR AND 10.6μm LIDAR.

THEY USED A GAMMA FUNCTION OF INDEX P TO DEFINE THE SIZE SPECTRUM

NEXT OHP SHOWS RATIO INDEPENDENT OF P AND GIVES PARTICLE SIZE.

NEXT TWO SLIDES SHOW THAT FOR LIDARS IN THE VISIBLE

THE BACKSCATTER RATIO IS A FUNCTION OF ICE DENSITY -

THIS LEADS TO AMBIGUITIES IN DERIVATION OF MEAN SIZE.

IN ACTUAL FACT THE SITUATION WILL BE MORE COMPLICATED -

ICE PARTICLES ARE NOT SPHERICAL BUT SHOULD USE RAY TRACING

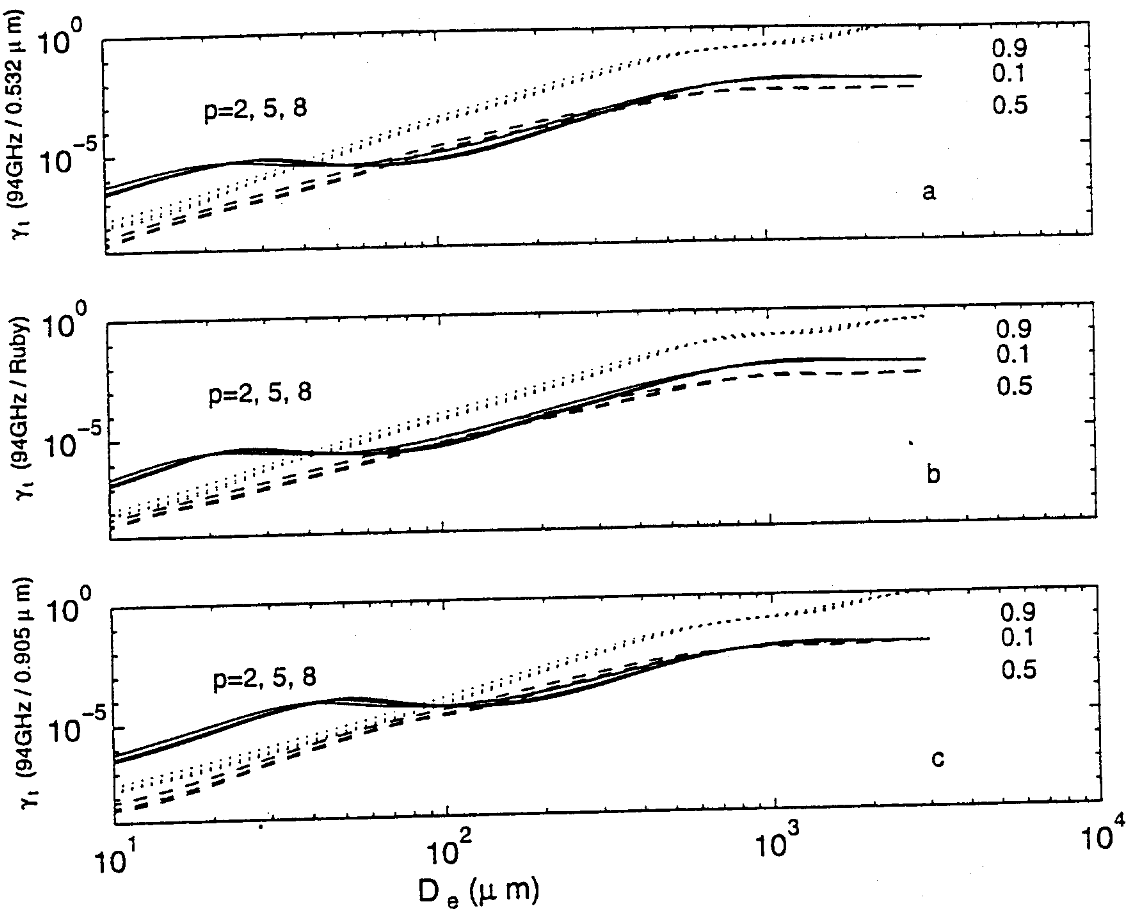
TECHNIQUES TO CALCULATE LIDAR BACKSCATTER FOR CRYSTAL FORMS.

CONCLUDE - DERIVATION OF SIZE BACKSCATTER RATIO OF RADAR TO

VISIBLE LIDAR MAY BE DIFFICULT.

17

Figure 3.4.8. Backscattering ratio (94GHz radar/lidar) variations with D_e for different particle densities ($\rho=0.1gcm^{-3}$: solid line; $\rho=0.5gcm^{-3}$: dashed line; $\rho=0.9gcm^{-3}$: dotted line). The three lines for each density are for p=2, 5 and 8 in gamma distribution.



CLASSIFICATION OF IWC - f(Z) BY TEMPERATURE AND SIZE.

BROWN ET AL CALCULATED AN ERROR IN IWC OF +50%/-30%

IF D* KNOWN WITH AN ACCURACY OF 50μm

IS IWC SPREAD REDUCED IF CATEGORISED BY TEMPERATURE?

IN NEXT FIGURE THE IWC - f(Z) ARE SPLIT UP INTO 6K

TEMPERATURE BANDS.

NOTE TEMPERATURE DEPENDENCE - AND REDUCED STANDARD DEVIATIONS

(6K APPROX 1Km, HEIGHT FROM RADAR ECHO, TEMP FROM NWP MODEL)

FOLLOWING TABLE SHOWS DIFFERENCE IN MEAN LOG(IWC)
FOR CEPEX AND EUCREX

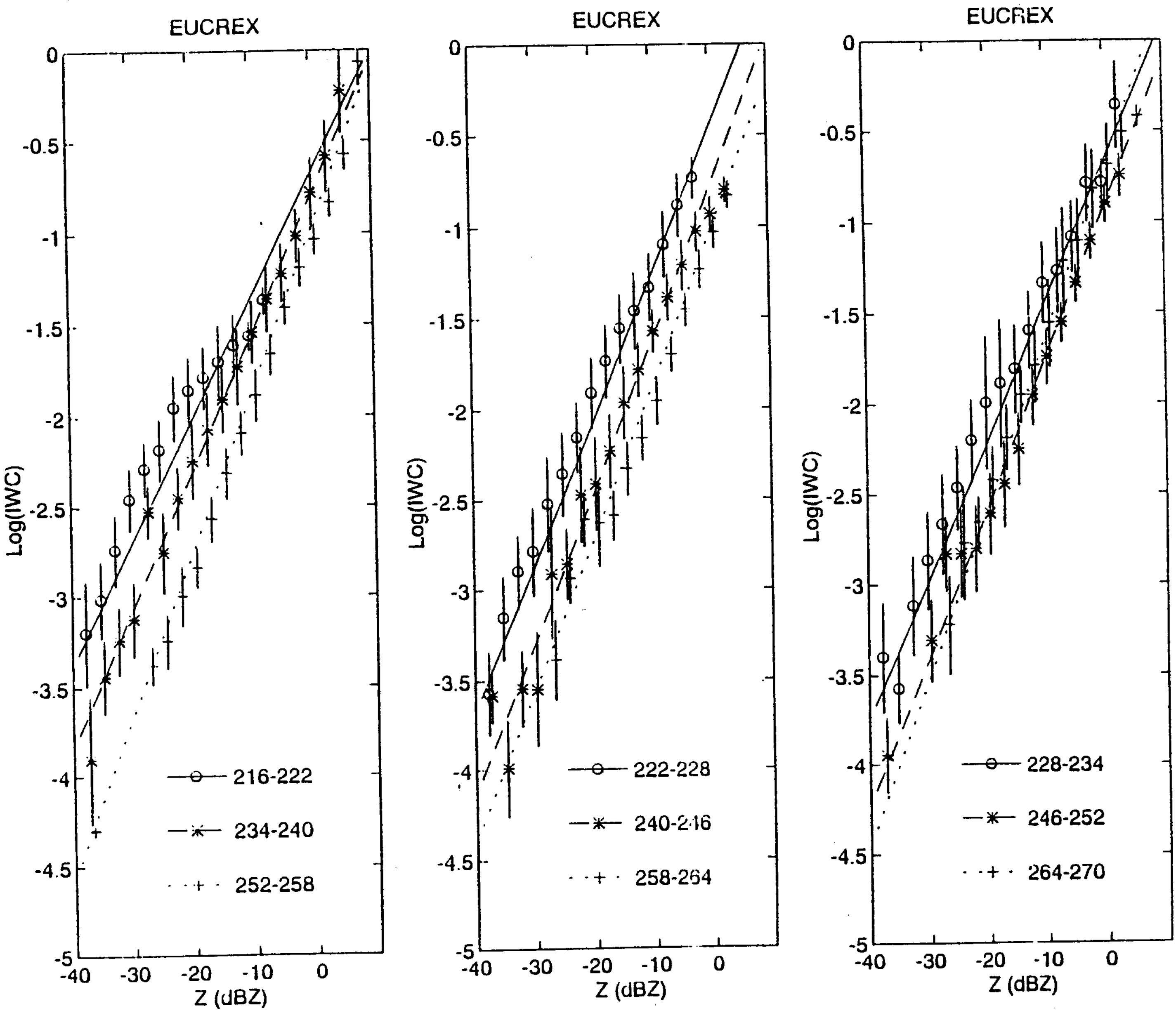
FOR MOST CLASSES WITH MORE THAN 20 POINTS,

DIFFERENCE IN MID-LAT AND TROPICAL IS

LESS THAN 0.1 (+25%/-20%)

20

Figure 3.4.14. The mean values of log(IWC) for data falling within 2.5dBZ ranges of Z. The error bars indicate plus and minus one standard deviation (For EUCREX data).



ACCURACY OF RETRIEVED ICE WATER CONTENT?

COMPARE ERRORS IN IWC FROM Z & D* WITH FROM Z & T

IF SPECTRA PERFECTLY EXPONENTIAL THEN IF ALL DATA ACCEPTED HAVE SAME D* - ERROR IN IWC TEND TO ZERO.

IN NEXT SLIDE DATA SPLIT UP INTO DIFFERENT VALUES OF D* AND WIDTH OF ACCEPTABLE D* IS ALTERED (FROM 10 TO 70μm)

ALSO IN EACH PANEL SYMBOLS SHOW ERROR FOR TEMPERATURE CLASSIFICATION.

1) ERRORS DO NOT INCREASE MUCH AS WIDTH OF D* CLASS INCREASE
   - IMPLIES DOMINANT ERROR IS DUE TO NON-EXPONENTIAL SPECTRUM

2) ERRORS BY TEMPERATURE CLASSIFICATION SIMILAR TO THOSE BY D*.

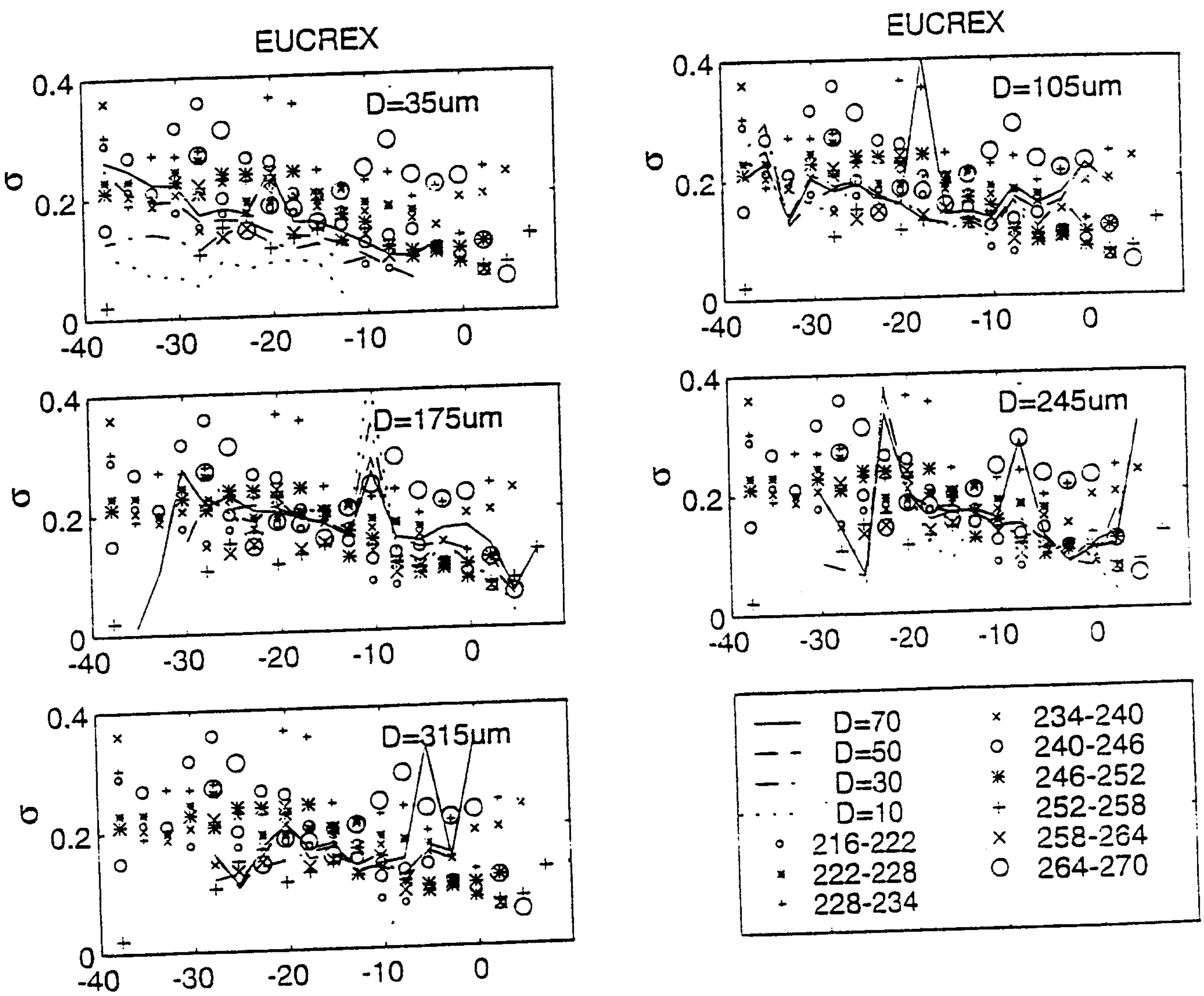
NEXT SLIDE SHOWS RESULTS FOR CEPEX (TROPICAL) DATA:
- CONCLUSIONS SIMILAR

(NOTE LARGE ERRORS FOR HIGH TEMP AND LOW Z PROBABLY BECAUSE OF LACK OF DATA POINTS)

CONCLUDE - NOT OBVIOUS THAT D* OUTPERFORMS T.

23

Figure 3.4.16. The standard deviation variations with radar reflectivity Z of step 2.5dBZ. Different symbol are for different D* and temperature ranges, the minimum data points within each range is greater than 5 (For EUCREX data).



ICE CONCLUSIONS

(i) RADIATIVELY SIGNIFICANT CLOUD.

THRESHOLD -30dBZ; OLR CHANGE 10W m^{-2};

DETECT 99.3% MID-LATITUDE AND 95.7& TROPICAL CIRRUS

(5W m^{-2}	-30dBZ	94%	80%
5/10W m^{-2}	-40dBZ	100%	100%

(ii) BECAUSE OF LOW DENSITY OF LARGER ICE PARTICLES,

ATTENUATION OF 78/94GHz SIGNAL NEGLIGIBLE.

(iii) SIZE DERIVATION FROM LIDAR/BACKSCATTER RATIO.

MAY WORK FOR 10.6μm LIDAR: VISIBLE LIDAR -

AMBIGUITIES DUE TO DENSITY CHANGE OF ICE WITH SIZE.

NEED LIDAR MODELS WITH REAL CRYSTALS.

(iv) DERIVATION OF IWC FROM Z AND SIZE OR Z AND TEMP.

IWC = f(Z) STANDARD DEVIATION OF LOG(IWC), σ, FACTOR OF TWO.

IWC = f(Z,D*) σ AS LOW AS 0.1 (+25%/-20%) FOR WARM CEPEX

σ COMMONLY 0.15 (+40%/-30%), CAN BE 0.2

DUE TO NON PERFECT EXPONENTIAL SIZE SPECTRA.

IWC = f(Z,T) BROADLY SIMILAR TO f(Z,D*),

σ CAN BE AS LOW AS 0.1 FOR WARM CEPEX.

COMPARING MEAN VALUES OF LOG(IWC) FOR TWO DATA SETS FROM

f(Z,T) GEOGRAPHICAL BIAS USUALLY LESS THAN 25%.

(v) EFFECT OF 10KM INTEGRATION LENGTH

DOES NOT CHANGE THE BIAS IN THE RETRIEVED IWC.

Dual-wavelength radar

- Use one radar which scatters in the Rayleigh regime and another at a higher frequency which scatters in the Mie regime. This way the **Dual Wavelength Ratio** (DWR) can be directly related to crystal size, where

$$\mathrm{DWR} = 10\log_{10}\left(\frac{Z_{\mathrm{low}}}{Z_{\mathrm{high}}}\right) \quad \mathrm{dB}$$

- Then calculate IWC from

$$\mathrm{IWC} = \frac{Z_{\mathrm{low}}}{R_{\mathrm{low}}(\mathrm{DWR})}$$

- Suitable frequencies which lie in the window regions of the atmospheric absorption spectrum are 35, 79/94, 140 and 215 GHz.

- The advantages of high frequencies are:
  - ◇ Higher sensitivity
  - ◇ Smaller footprint from space
  - ◇ Larger DWR for a given size
  - ◇ Better correlation between Z and IWC.

- But they suffer much more attenuation in the boundary layer.

Dual-wavelength radar in space

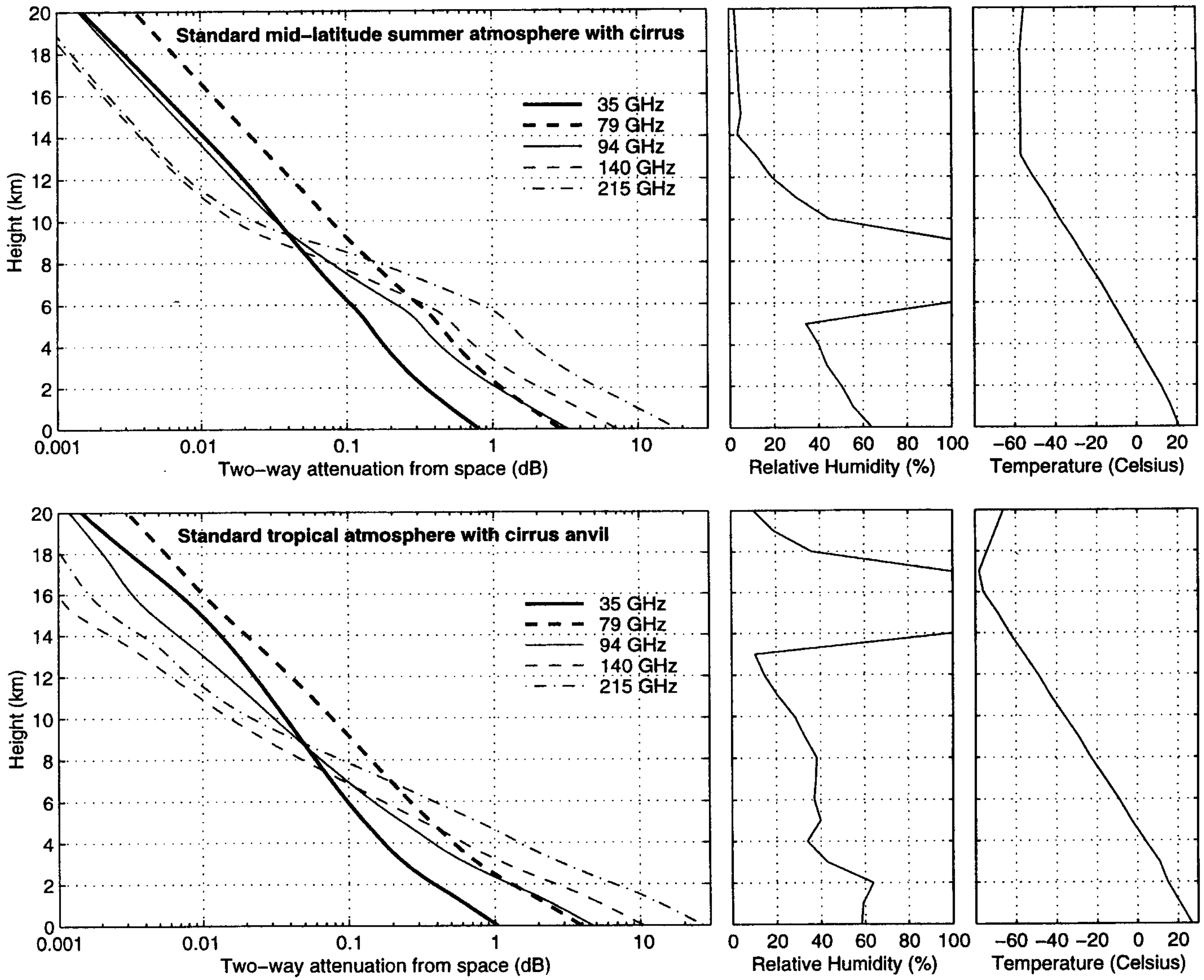
- From space to the melting-level, the 2-way gaseous attenuation at 215 GHz is at most around 2 dB.

- With present technology a spaceborne 94 GHz radar could detect down to −30 dBZ.

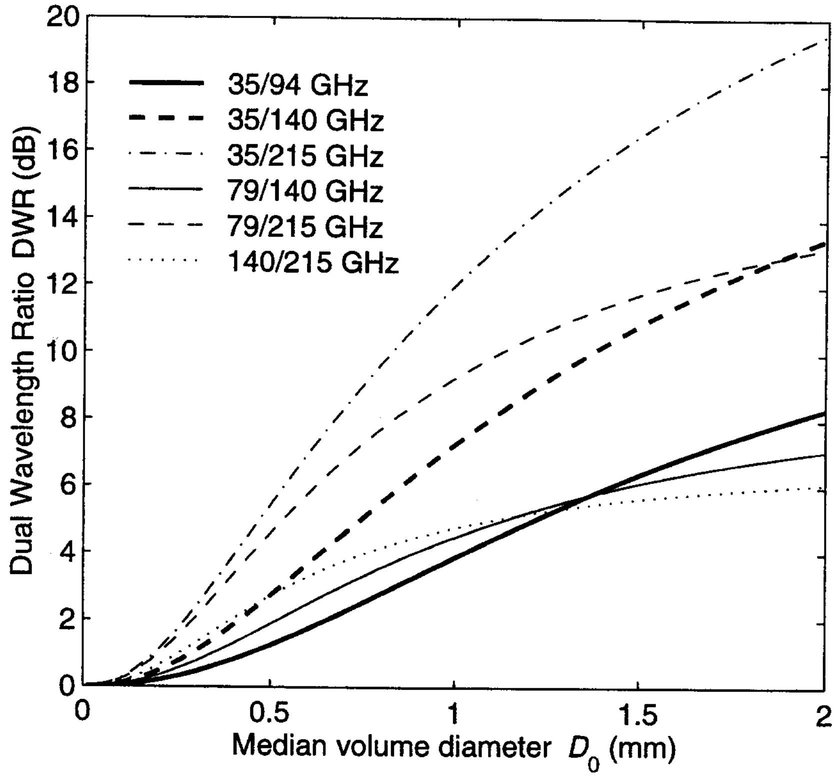
- Reflectivity at each frequency has been calculated using over 20,000 aircraft size spectra taken during EUCREX and CEPEX.

- A random error has been added to the data to simulate the natural fluctuation of radar reflectivity. This increases at low signal-to-noise ratios.

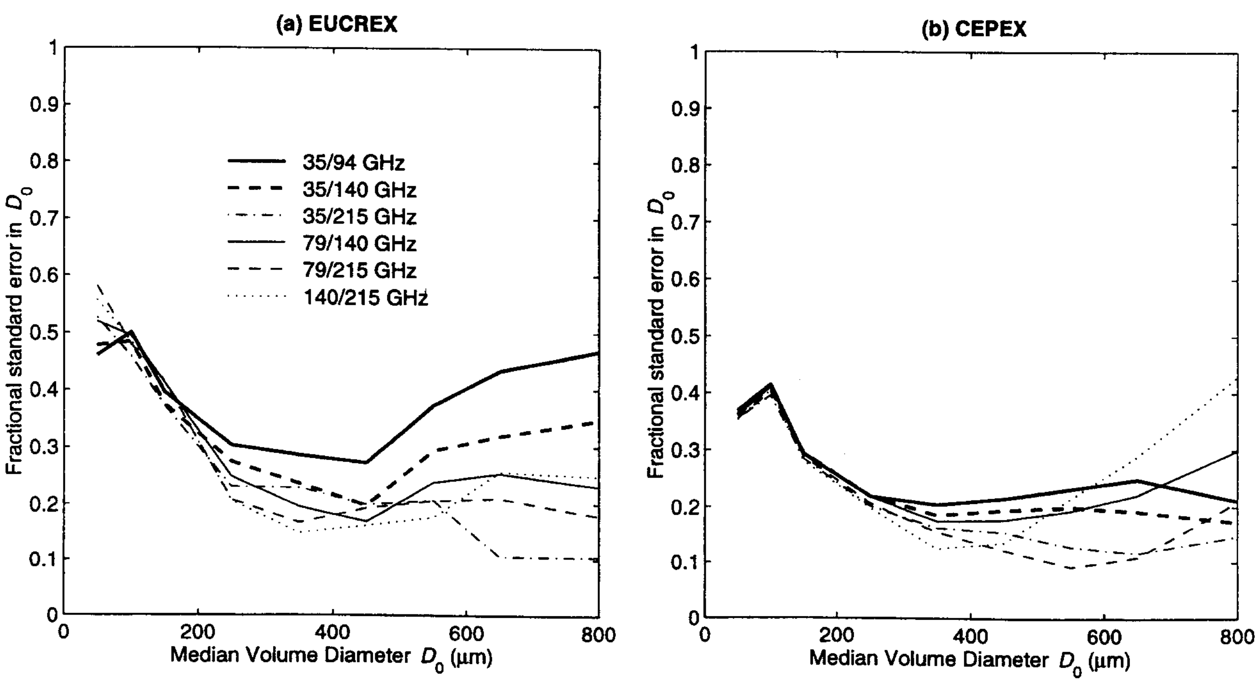
- Must consider problem of different beamwidths, and also if putting the instruments on separate satellites (the "Split Mission" scenario) would drastically reduce the accuracy.



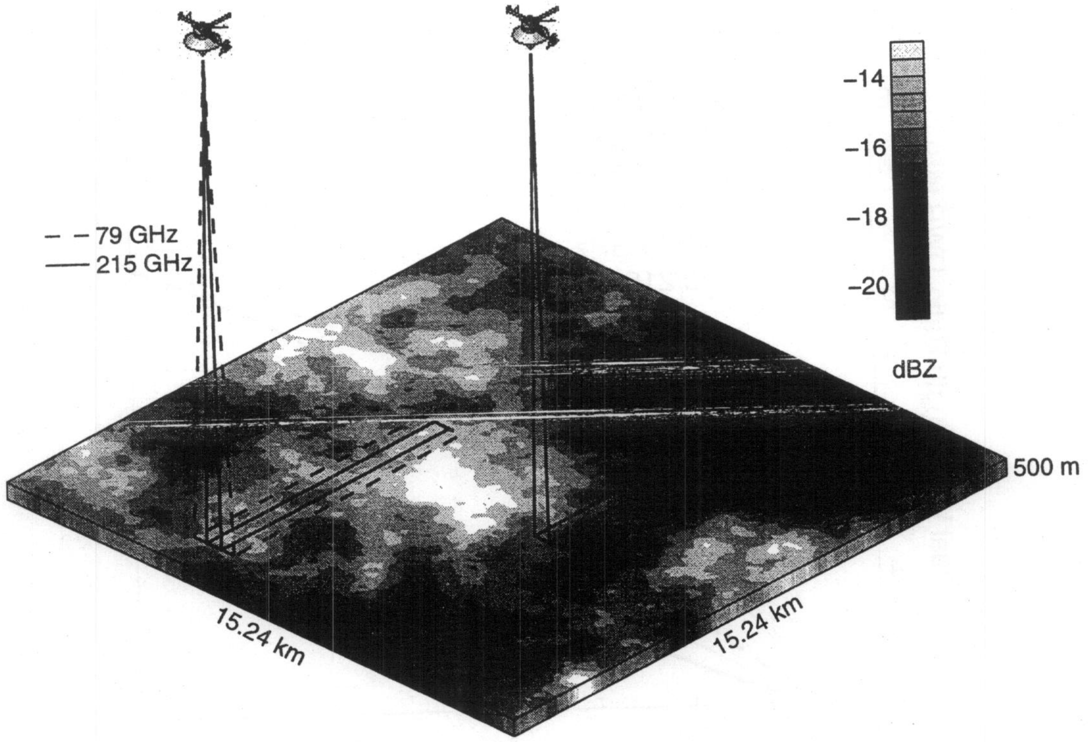
The two-way attenuation from space at the frequencies 35, 79, 94, 140 and 215 GHz for two standard atmospheres with cirrus layers added at appropriate altitudes. The temperature and relative humidity profiles are shown to the right.



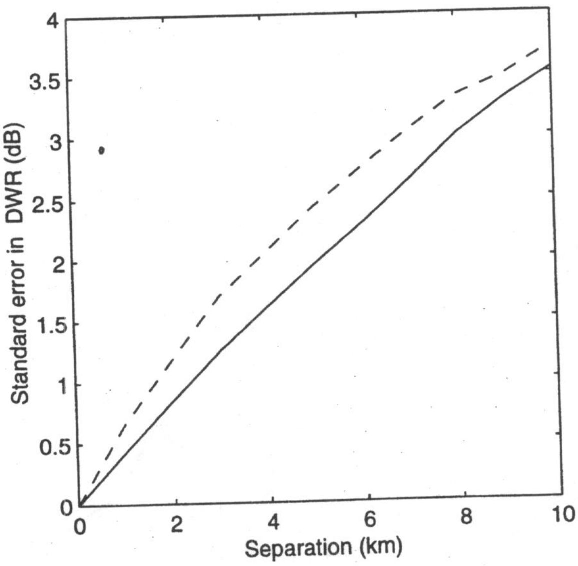
Dual-wavelength ratio as a function of median volume diameter D_0 for an exponential distribution of cirrus crystals and six different frequency combinations.



Error in retrieved D_0 as a function of D_0 for six different frequency combinations.



Schematic of a spectrally realistic cloud field, illustrating the difference in swath sizes for a dual-wavelength 79/215 GHz radar mounted on a single satellite, and the typical configuration for the 'Split Mission' scenario with satellites separated by 5 km in both the along- and cross-track directions.



Error in DWR as a function of swath separation in the Split Mission scenario. The solid line corresponds to satellites in the same orbit but one lagging the other and the dashed line is for satellites in adjacent orbits.

Conclusions

- The potential of the dual-wavelength method to measure crystal size in cirrus clouds has been demonstrated from the ground using 35 and 94 GHz radars.

- Aircraft validation is essential; should be possible in CLARE'98.

- Crystal density is an uncertainty which needs to be addressed, but the problem of aspect ratio can be largely eliminated by viewing at an elevation of 45°.

- The most promising combination for a spaceborne system would be 79/215.

- Size measurement is too inaccurate to be useful in the lowest 10–15 dB of sensitivity. Above this the 79/215 combination can measure IWC with an error of less than ±30%.

- The "Split Mission" scenario makes the radar/radar technique unworkable—probably also true for the lidar/radar technique.

II. SYSTEM

INTRODUCTION

W. LEIBRANDT, ESA, EOPP

THE ERM SYSTEM

- STUDY OBJECTIVES
- PROJECT HISTORY
- SYSTEM EVOLUTION
- INTERNATIONAL CONTEXT

STUDY OBJECTIVES

- ACCOMMODATE THE SET OF PAYLOAD INSTRUMENTS CONSISTING OF THE CLOUD RADAR, THE BACKSCATTER LIDAR, THE CLOUD IMAGER AND THE BROADBAND RADIOMETER ON A SINGLE OR A TANDEM MISSION.
- FLY THE SATELLITE IN A SUN-SYNCHRONOUS ORBIT WITH A 1400 HRS NODAL CROSSING TIME.
- OPERATE THE SATELLITE FOR AT LEAST TWO YEARS, SIZING CONSUMABLES FOR AN OPTIONAL THIRD YEAR.
- OPERATE THE GROUND SEGMENT FOR DATA ACQUISITION, PRE-PROCESSING, ARCHIVING AND DISSEMINATION.

PROJECT HISTORY

- REQUIREMENTS AND CONSTRAINTS FOR NEW MISSIONS AND PAYLOADS, 1995, TWO PARALLEL STUDIES WITH MMS-F AND SPACE SYSTEMS FINLAND
- USER CONSULTATION WORKSHOP, GRANADA, 1996
- INTERMEDIATE CLASS MISSIONS, 1996, THREE PARALLEL STUDIES WITH MMS-F, ALENIA AND AEROSPATIALE.
- 03 JULY 1998, KICK-OFF MEETING PHASE A STUDY, MMS-F
- NUMEROUS STUDIES FOR SCIENCE AND INSTRUMENT ISSUES

SYSTEM EVOLUTION

- GRANADA: 2500 KG, 1600 W, ARIANE 5, 600 KM ORBIT, MANDATE TO SIMPLIFY THE MISSION
- ICM STUDIES: <1500 KG, 1100 W, 411 - 450 KM ORBIT, MEDIUM CLASS LAUNCHER (PSLV, CYCLONE, LM)
- MMS-F PHASE A PROPOSAL: 1100 KG, 1000 W, 411 - 450 KM ORBIT, SMALLER LAUNCHER (EUROCKOT, LMLV-2)
- START OF PHASE A: MISSION LIFE REDUCED TO 2 YEARS, ATMOSPHERIC SOUNDING DESCOPED FROM MISSION
- THE PHASE A STUDY IS TO OPTIMISE THE SYSTEM AS A WHOLE, INCLUDING ALL ELEMENTS.
- AGGRESSIVE APPROACH TO MISSION IMPLEMENTATION

INTERNATIONAL CONTEXT

- ATMOS-B2, RADAR, LIDAR, VIS/IR IMAGER, (MICROWAVE IMAGER), ((BBR)), LAUNCH IN 2005
- ELISE (MDS-LIDAR), NASDA, CONCEPT DEMO MISSION, 1 YEAR MISSION, FEB. 2001, 550 KM ORBIT, 30 DEG. INCLINATION
- CLOUDSAT, PROPOSED AS ESSP MISSION, JPL, CLOUD RADAR, A-BAND SPECTROMETER/IMAGER, SUBMM RADIOMETER, TANDEM MISSION WITH ICESAT
- PICASO, LIDAR CLOUD AND AEROSOL MISSION, NASA LANGLEY,

II. SYSTEM

SYSTEM CONCEPTS FOR THE EARTH EXPLORER EARTH RADIATION MISSION

P. MERAT, MMS-F

EOPP Seminar On Radiation Studies

ESTEC - September 1st 1998

MMS Contribution

« System Concepts for the Earth Explorer Earth Radiation Mission »

Overview of the Phase A study content and objectives

ERM Study Objective

- **Objective = To establish a ERM concept which is both technically feasible and affordable within the Earth Explorer Mission context.**

- **Study context :**
  - ⇨ In order to satisfy the mission objectives, the ERM satellite needs to carry several instruments, including two relatively complex active instruments (ATLID and CPR) => high strain on system complexity and cost
  - ⇨ Over the period 1995-98, various optimisation exercises have lead to a decrease of the spacecraft size from a large size (2500 kg at Grenada) to a medium (1500 kg , ICM study - 1997) and then small-to-medium size (1100 kg in MMS ERM proposal)

- **Investigation areas :**
  - ⇨ possibility of further decreasing the altitude of the operational orbit
  - ⇨ validity of reduced payload complements and/or two satellite scenarios
  - ⇨ potential for further reducing the spacecraft and instrument complexity and cost
  - ⇨ optimum use and share of on-board resources
  - ⇨ re-use of off-the-shelf hardware
  - ⇨ cost-effective development plan

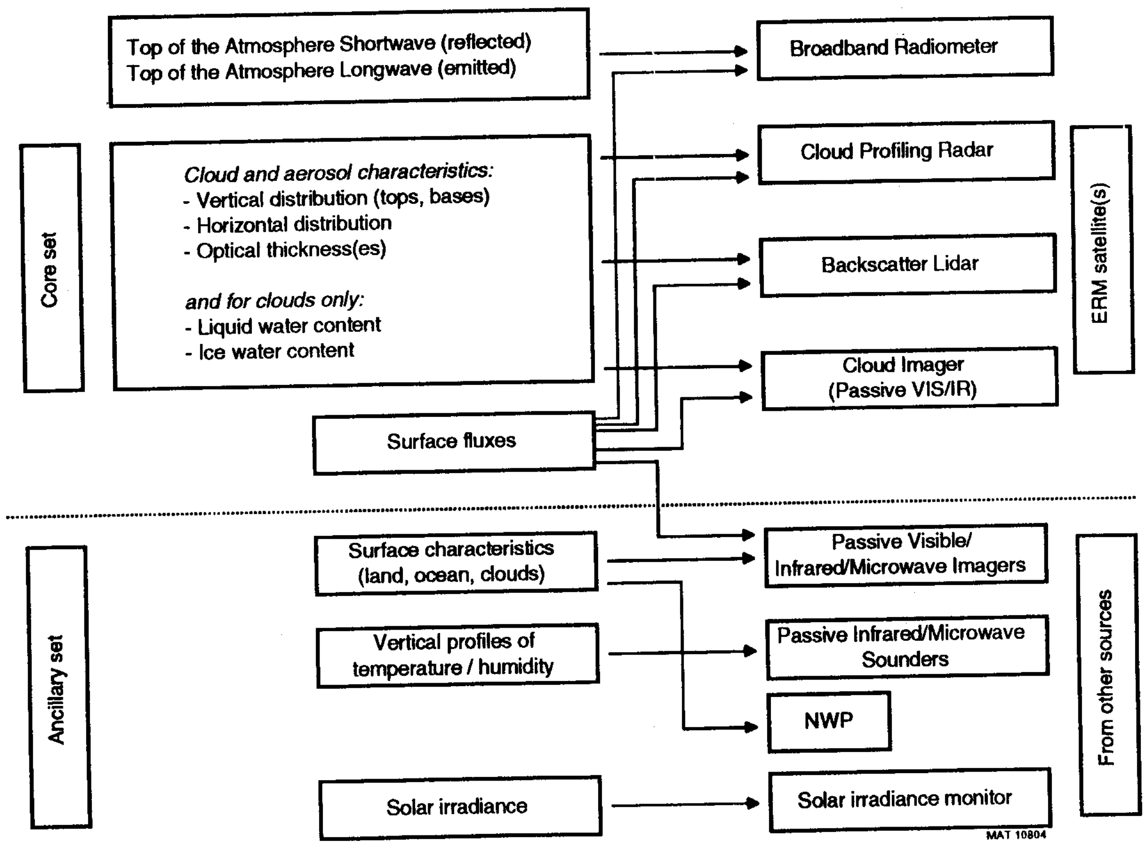
ERM Study Approach

Phase	Title	Objective	Duration	ESA review
1	System Concept Definition	Mission + System level trade-offs Selection of a preferred system concept	5 months	Progress Meetings
				Preliminary Concept Review (PCR - Dec 98)
2	System Concept Development	Development of the baseline system concept design to establish feasibility	5 months	Progress Meetings
				Preliminary Requirements Review (PRR – May 99)
3	System Concept Consolidation and Cost Estimate	Consolidation of concept design and final programmatic analysis	2 months	Programmatics Meeting

ERM : Mission Objective

To provide a set of cloud profiling and aerosol observations over 2 years by:

- **measuring the vertical structure of cloud and aerosol fields** and their horizontal distributions over all climate zones;
- **measuring radiation budget components** at the top of the atmosphere simultaneously



ERM : System Overview

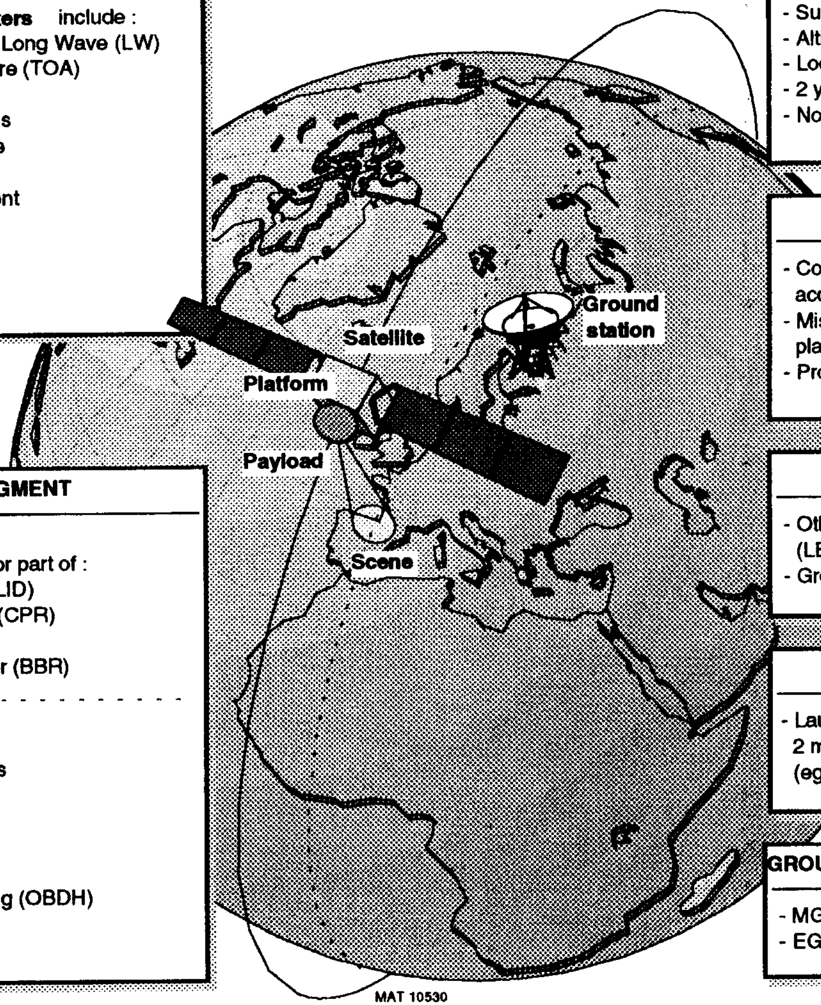
'SCENE'

Measurement parameters include :
- Short Wave (SW) and Long Wave (LW) flux at top of atmosphere (TOA)
- Clouds
  - Layer tops / bottoms
  - Fractional coverage
  - Optical thickness
- Liquid / ice water content
- Effective particle size
- Aerosols
- Temp / H_2O profiles
- Surface emissivity

SPACE SEGMENT

Payload to include all or part of :
- Backscatter Lidar (ATLID)
- Cloud Profiling Radar (CPR)
- Cloud Imager (CI)
- Broadband Radiometer (BBR)

Platform :
- Structure
- Mechanisms and pyros
- Thermal control
- Propulsion
- Power and energy
- AOCS
- Onboard Data Handling (OBDH)
- Communications
- Onboard software



MISSION FACTORS

- Sun synchronous orbit
- Altitude 300 - 500 km
- Local time 14 00
- 2 years mission life
- Nominal launch 2005

GROUND SEGMENT

- Command and data acquisition (eg Kiruna)
- Mission & satellite control and planning
- Processing and archiving

AUXILIARY DATA SETS

- Other space mission (LEO, GEO)
- Ground based data

LAUNCH VEHICLE

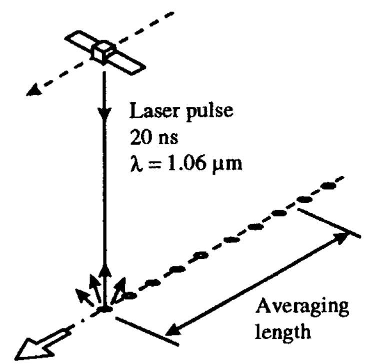
- Launch compatibility with at least 2 medium-size vehicles (eg ROCKOT, ATHENA)

GROUND SUPPORT EQUIPMENT

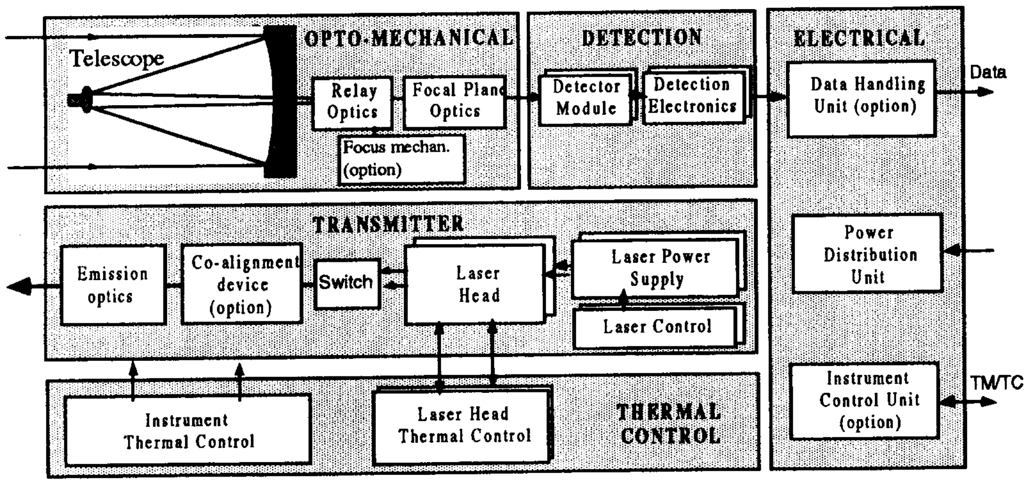
- MGSE
- EGSE

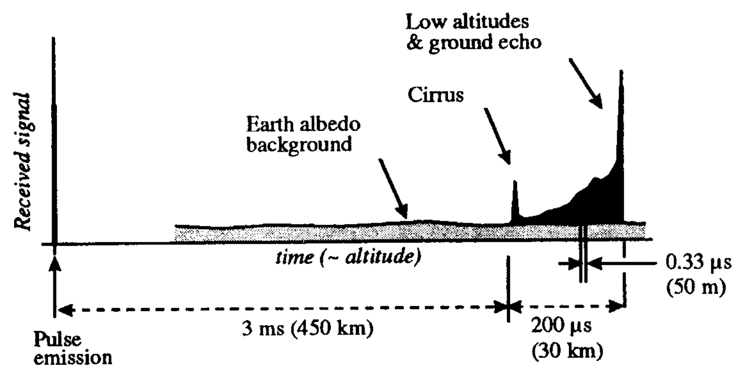
Summary of ATLID Requirements for ERM

- **Requirements Summary :**
  - ⇨ NdYAG laser operating at 1.06 micron wavelength
  - ⇨ Continuous operation with nadir view only, in footprint < 200 m diameter
  - ⇨ Vertical resolution < 100 m over altitude range 0 < h <30 km
  - ⇨ Set of echoes averaged over 10 km horizontal distance
  - ⇨ SNR specified for a range of atmospheric/cloud conditions



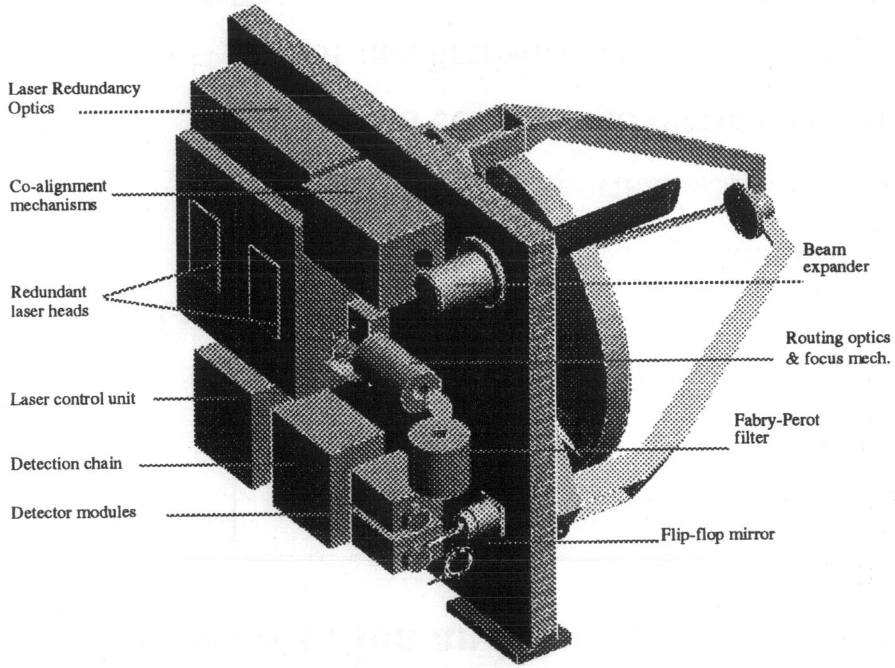
- **Major Functions of the ATLID Instrument:**

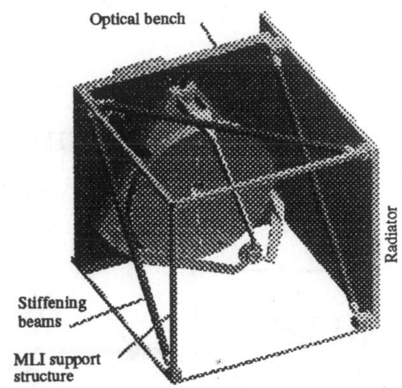


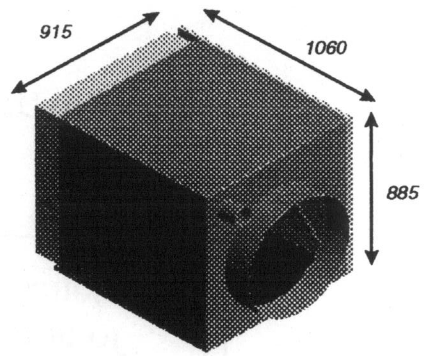


ATLID Concept (Proposal Reference)

- **Main Characteristics of Proposal Reference Design :**
  - ⇨ Diode-pumped laser : 70 mJ ; 50 Hz PRF.
  - ⇨ 60 cm diameter collector; IFOV equivalent to 160 m dia (from 410 km altitude)
  - ⇨ Avalanche Si photodiode detectors (ambient temperature)
  - ⇨ Laser head thermal control by 2-phase fluid-loop or variable conductance heat-pipes
  - ⇨ Total instrument mass of 170 kg, mean power demand 225 W and data rate 600 kbps







ATLID Trade-offs in ERM Phase 1

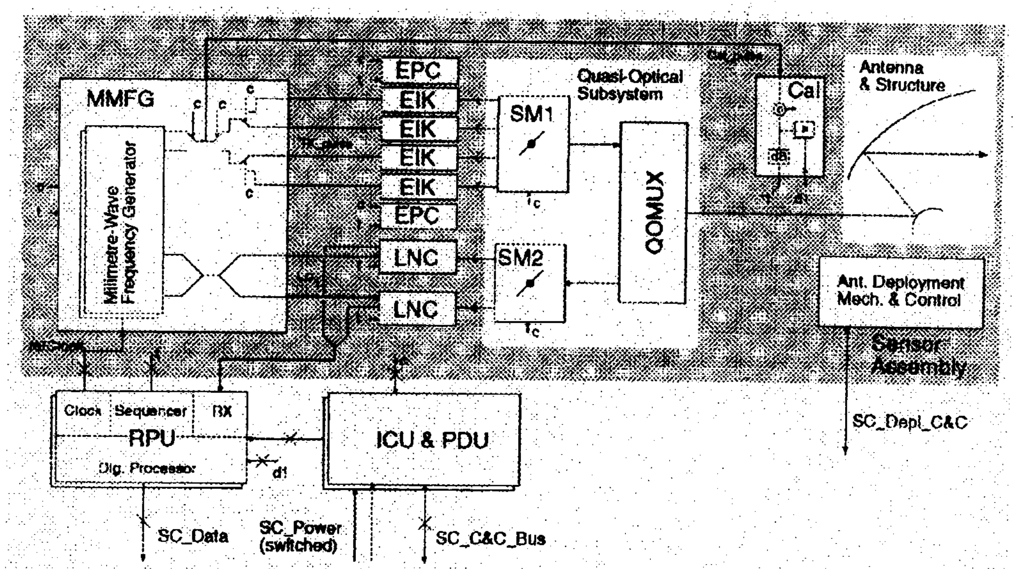
- **Optimisation and Performance Evaluation**

Requirements Analysis and Revision → Performance Evaluation SW → Optimisation of ATLID Parameters

- **Trade-offs**
  - ⇨ Opportunities provided by reductions in lifetime and altitude (power, diameter)
  - ⇨ Opto-mechanical-thermal accommodation
  - ⇨ Laser head concept and thermal control
  - ⇨ Use of mechanisms (Refocus; Tx/Rx co-alignment) vs highly stable receiver optics
  - ⇨ Telescope design and materials
  - ⇨ Number of detection channels and detection chain design
  - ⇨ Reliability and redundancy approach
  - ⇨ Electrical architecture
- **Evaluation Criteria**
  - ⇨ Performance, feasibility, schedule, etc but above all **cost**

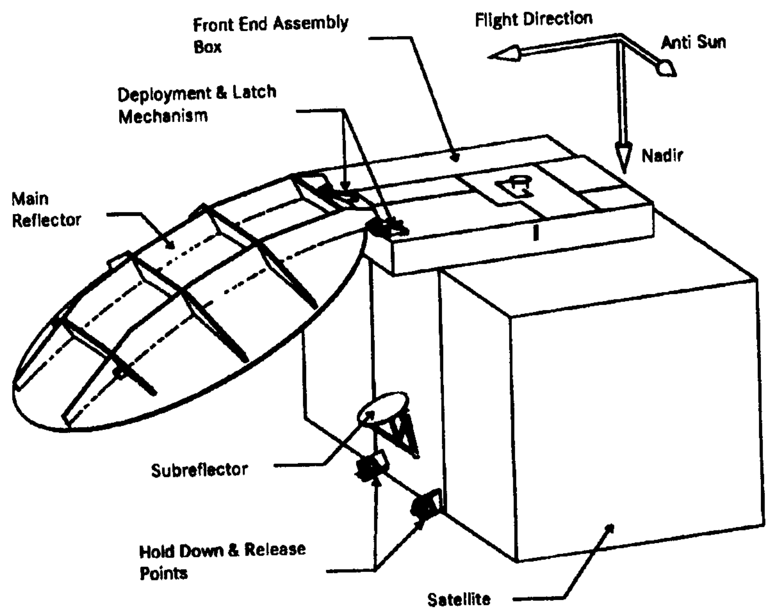
Summary of CPR Requirements for ERM

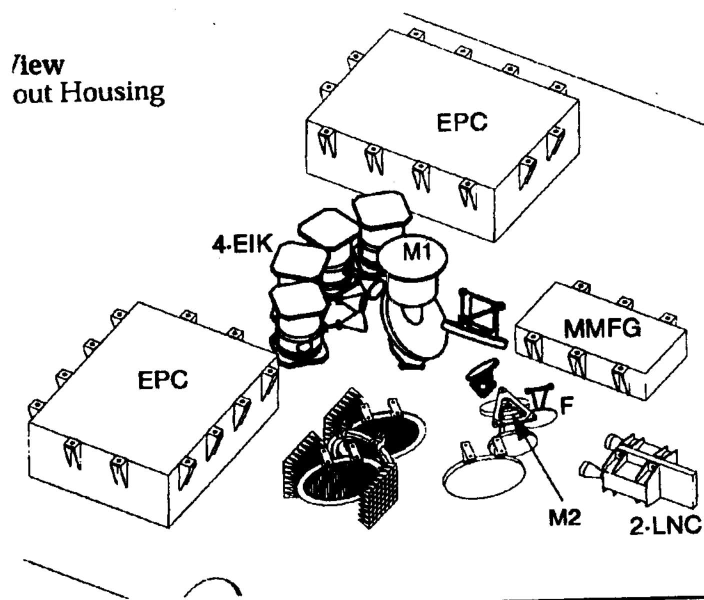
- **Requirements Summary :**
  - ⇨ 94 GHz linearly polarised radar
  - ⇨ Continuous operation with nadir view only, in footprint < 1000 m diameter
  - ⇨ Vertical resolution < 500 m over altitude range 0.5 < h <20 km
  - ⇨ Echoes averaged incoherently onboard over 1 km distance
  - ⇨ Performance specified for a range of atmospheric conditions in primary and secondary modes of operation
- **Major Functions of the CPR Instrument:**



CPR Concept (Proposal Reference)

- **Main Characteristics of Proposal Reference Design (at 410 km) :**
  - ⇨ High peak power (> 1 kW) unmodulated transmitted pulses at about 6000 Hz PRF
  - ⇨ Cassegrain dual-offset antenna (approx 2 m dia) with deployable main reflector
  - ⇨ Extended Interaction Klystron (EIK) high power amplifier (HPA) tubes driven by electrical power conditioners (EPC)
  - ⇨ Quasi-optical multiplexer assembly plus low noise converter cooling, need TBC
  - ⇨ Approx. instrument mass 125 kg, mean power demand 200 W and data rate 30 kbps





CPR Trade-offs in ERM Phase 1

- **Optimisation and Performance Evaluation**

Requirements Analysis and Revision $\xrightarrow[\text{Evaluation SW}]{\text{Performance}}$ Optimisation of CPR Parameters

- **Main Areas for Trade-off and Optimisation**
  - ⇨ Opportunities provided by reductions in lifetime and altitude (power, diameter)
  - ⇨ RF/mechanical/thermal configuration & accommodation of antenna, FEA, etc
  - ⇨ HPA technology and thermal design
  - ⇨ LNC technology and operating temperature
  - ⇨ Reliability and redundancy approach
  - ⇨ Sensitivity wrt instrument timing, noise measurement, calibration, etc
  - ⇨ Electrical architecture
- **Evaluation Criteria**
  - ⇨ Performance, feasibility, schedule, etc but above all **cost**

Summary of Cloud Imager Requirements for ERM

⇨ 5 channel, passive nadir sounder imaging a continuous strip along track

⇨ Data from visible/NIR/SWIR only useful on 'day' side of orbit

⇨ Spatial sampling interval < 1000 m at subsatellite point

• Spectral bands	B1 : 0.649 - 0.669 µm (VIS)	B4 : 8.5 - 9.4 µm (TIR1)*
	B2 : 0.885 - 0.875 µm (NIR)	B5 : 10.4 - 12.4 µm (TIR2)*
	B3 : 1.58 - 1.64 µm (SWIR)	

(*Specifications of width of bands 4 and 5 are the latest figures for uncooled microbolometer concept)

• Swath width	To be optimised in the range 100 to 300 km for all bands	
• Coregistration	Better than 0.1 sampling distance (TBC) between spectral bands	
• Radiometric reqts	Bands 1, 2, 3	Bands 4 & 5
• Dynamic range, max	Albedo 1. 3 @ 30° sun zenith angle	Scene at 180 K
min	Albedo 0.1 @ 30° sun zenith angle	Scene at 350
• Signal to Noise Ratio	> 200 @ max radiance	NEDT < 0.25 K @ 300 K
	> TBD @ min radiance	NEDT< TBC @ 200 K
• Absolute accuracy	< 10% of estimated reflectance	< 1 K @ 300 K

CI Concept

- **Main Characteristics of Early Phase A Reference Design :**
  - ⇨ Pushbroom imager using off-the-shelf detectors taken as reference in proposal phase.
  - ⇨ Proposal reference design characteristics were: 27 kg; 95 W (with active cooling).
  - ⇨ Uncooled micro-bolometer concept also described and now much preferred.
  - ⇨ This concept was investigated by OG in a study of Uncooled Thermal IR Imagers.
  - ⇨ Microbolometer concept characteristics are: ~ 12 kg; 45 W (uncooled); mean data rate of ~ 50 kbps (for a 1 km sample interval and 100 km swath width).

Functional block diagram of OG instrument (OG final presentation)

3D colour view of OG instrument (OG final presentation)

BBR Requirements for ERM

- **Requirements Summary :**
  - ⇨ Passive nadir sounding with 2 spectral bands :
    - ➢ Short wave (SW) - 0.2 to 4 micron) Alternative channels to be implemented
    - ➢ Long-wave (LW) - 4 to 50 micron) as necessary or appropriate
  - ⇨ Swath width: Single pixel (30 km) up to CI swath (100 - 300 km)
  - ⇨ Spatial sampling interval : 30 km at subsatellite point
  - ⇨ Radiometric accuracy: 0.5 W/m^2Sr in SW and LW channels
  - ⇨ Absolute accuracy: 1.5 % in SW and LW channels
- **Phase 1 Concept Assessments:**
  - ⇨ Proposal reference was based on US CERES instrument for which the main characteristics are: 45 kg; 50 W; 10 kbps.
  - ⇨ Various concepts derived from existing designs will be analysed; options under investigation include derivatives of: CERES; SCARAB (OPERA); GERB.
  - ⇨ A multipixel BBR concept, specifically designed for ERM, is currently being studied by REOSC/Sfim (5pixels, 120 km swath). This design offers much reduced size, mass and power : 200 x 200 x 200 mm; 6 kg; 20 W; < 3 kbps. These figures are now assumed with some margin (10 kg and 25 W used in new payload budget).

ERM Payload Resource Totals and Design Drivers

	Mass (kg)	Power (W)	Data (kbps)	Size
ATLID	167	225	600	~ 2 m dia antenna plus FEA of 2 x 1.3 x 0.3 m
CPR	127	195	30	Approx. 1 m cube
Cloud Imager	12	45	50 (mean)	~ 0.5 x 0.4 x 0.2 m
BBR	10	25	10	~ 0.2 x 0.2 x 0.15 m
Total, approx	**316 kg ***	**490 W ***	**700 kbps**	

(* *Proposal totals were 380 kg, and 596 W including GRAS and cooled Cloud Imager).*

- The figures are appropriate to the proposal reference mission assumptions on orbit altitude (410 km) and nominal life (4 yr); further reductions are being sought.

- Additional instrument design drivers relate to:
  - ➢ Mechanisms (e.g. CPR antenna deployment)
  - ➢ Lifetime (ATLID/CPR transmitters)
  - ➢ Thermal Control (ATLID, CPR, CI)
  - ➢ EMC/RFI (CPR)

Mission Assessments and Trade-Offs

- In the first two months of ERM Phase A the industrial team is analysing requirements, seeking **relaxations in design/cost drivers** and trading off alternative options in **all areas** (mission, system, payload, platform, etc).
- For the overall ERM mission, **key aspects** being addressed include:
  - ⇨ Mission implementation
    - ➤ Full and reduced payloads
    - ➤ Single and split-satellite scenarios
  - ⇨ Mission life
  - ⇨ Scene coverage
  - ⇨ Orbit characteristics
    - ➤ Altitude
    - ➤ Local time
  - ⇨ Launcher
  - ⇨ Ground segment

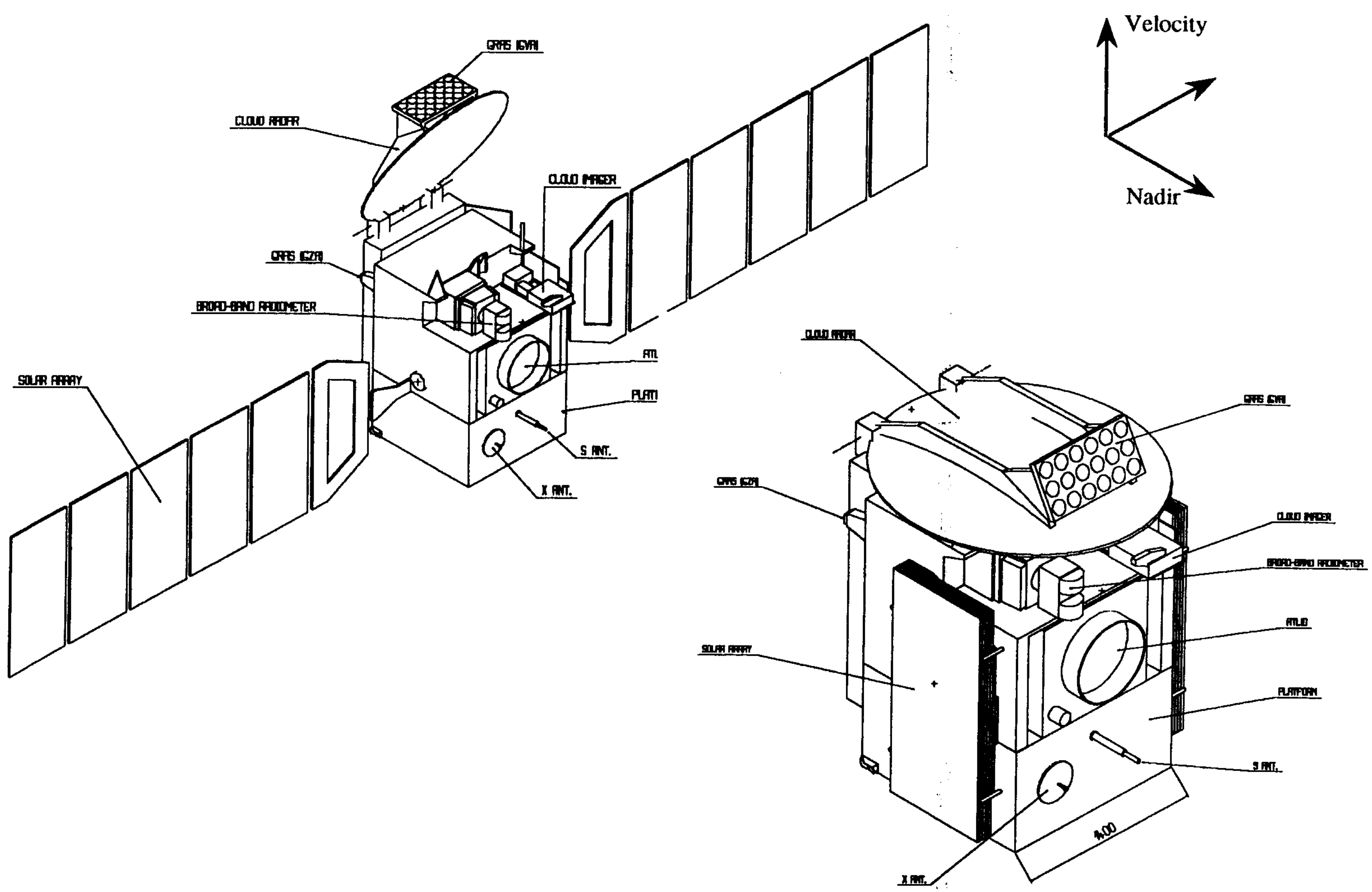
Orbit Altitude Options & Trade-Offs

- Optimum operating orbit altitude is high on the list of areas to assess.
- A key point in the proposal was the reduction in payload demand (size, power), compared to earlier studies, which was achieved in coming down ~ 400 km.
- We are now investigating even lower altitudes and, to support this activity, we have assessed the parametric dependence of instrument performance:
  - ⇨ the basic parametric expressions relating SNR, aperture, transmitter power (in the case of the active instruments), etc to orbit altitude
  - ⇨ the resulting scope for reducing physical characteristics of antenna/optical unit and electronics (size, mass, input power, etc) for altitude decrease
- In parallel we have investigated the impacts for S/L design and launch including:
  - ⇨ Launcher capability versus altitude
  - ⇨ Air density/drag effects and means to maintain orbit altitude and satellite attitude, notably propulsion system type, propellant quantity, wheel size, etc.
  - ⇨ Atomic oxygen degradation effects
  - ⇨ Communications and ground segment interfaces

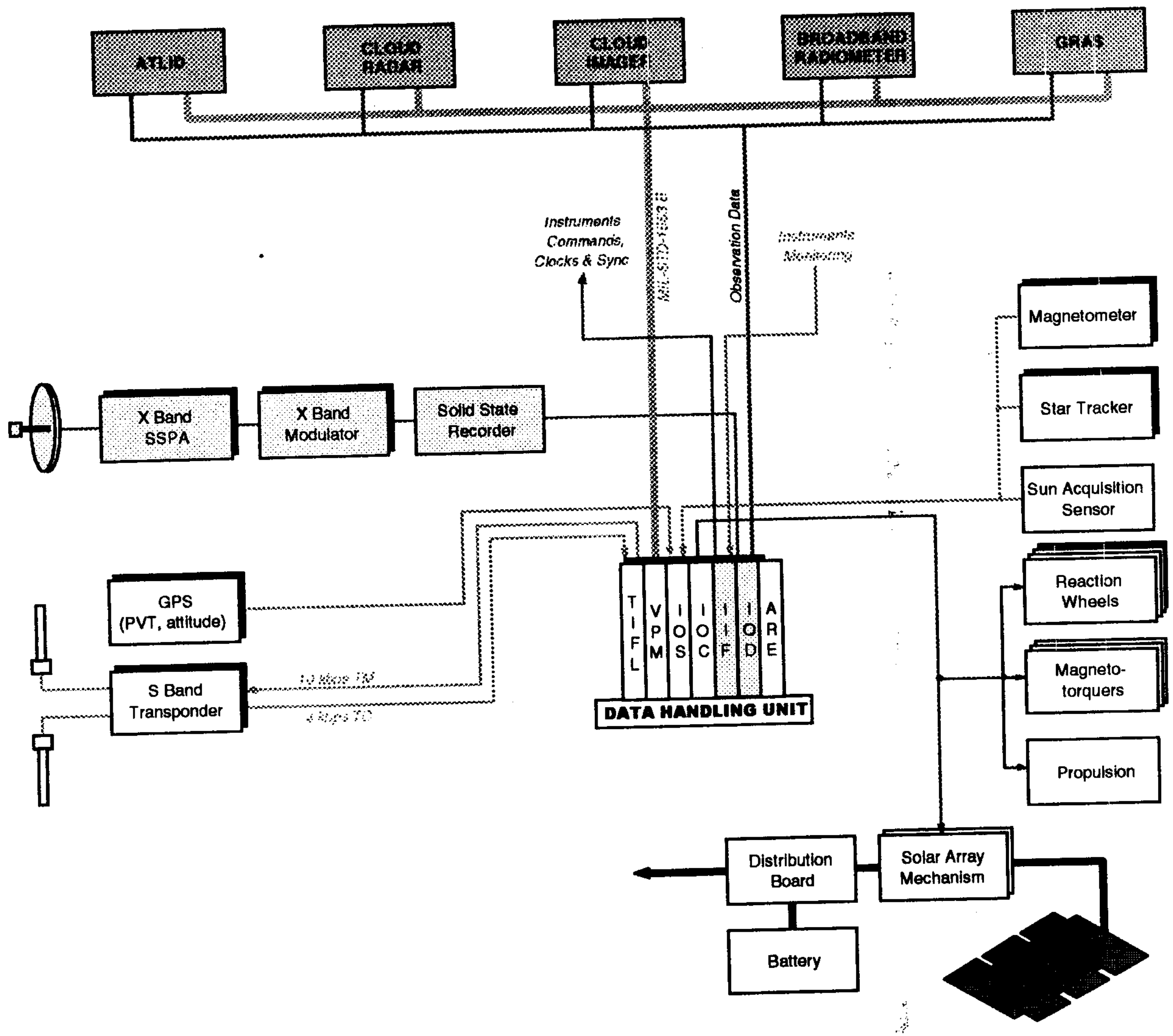
Payload/Spacecraft Design Options & Trade-Offs

- Clearly the designs at the level of individual instruments, overall payload, platform, etc are highly interactive.
- Individual instrument analysis and optimisation is being made with respect to:
  - ⇨ revised requirements
  - ⇨ alternative design/technology concepts
  - ⇨ varying orbit characteristics, etc
  - ⇨ alternative instrument-platform mounting options
- At overall spacecraft configuration level we are assessing various options for:
  - ⇨ Alternative arrangements of instrument assemblies wrt nadir, side, zenith faces
  - ⇨ Modularity - fully integrated or separate wrt mech/ thermal, electrical aspects
  - ⇨ Heritage - new architecture, adaptation, at system and subsystem levels
  - ⇨ Spacecraft geometry - solar array deployment/rotation, symmetry, body aspect ratio..
  - ⇨ Thermal control
  - ⇨ etc

Proposal Concept : Spacecraft Overview



Proposal Concept : Spacecraft Architecture

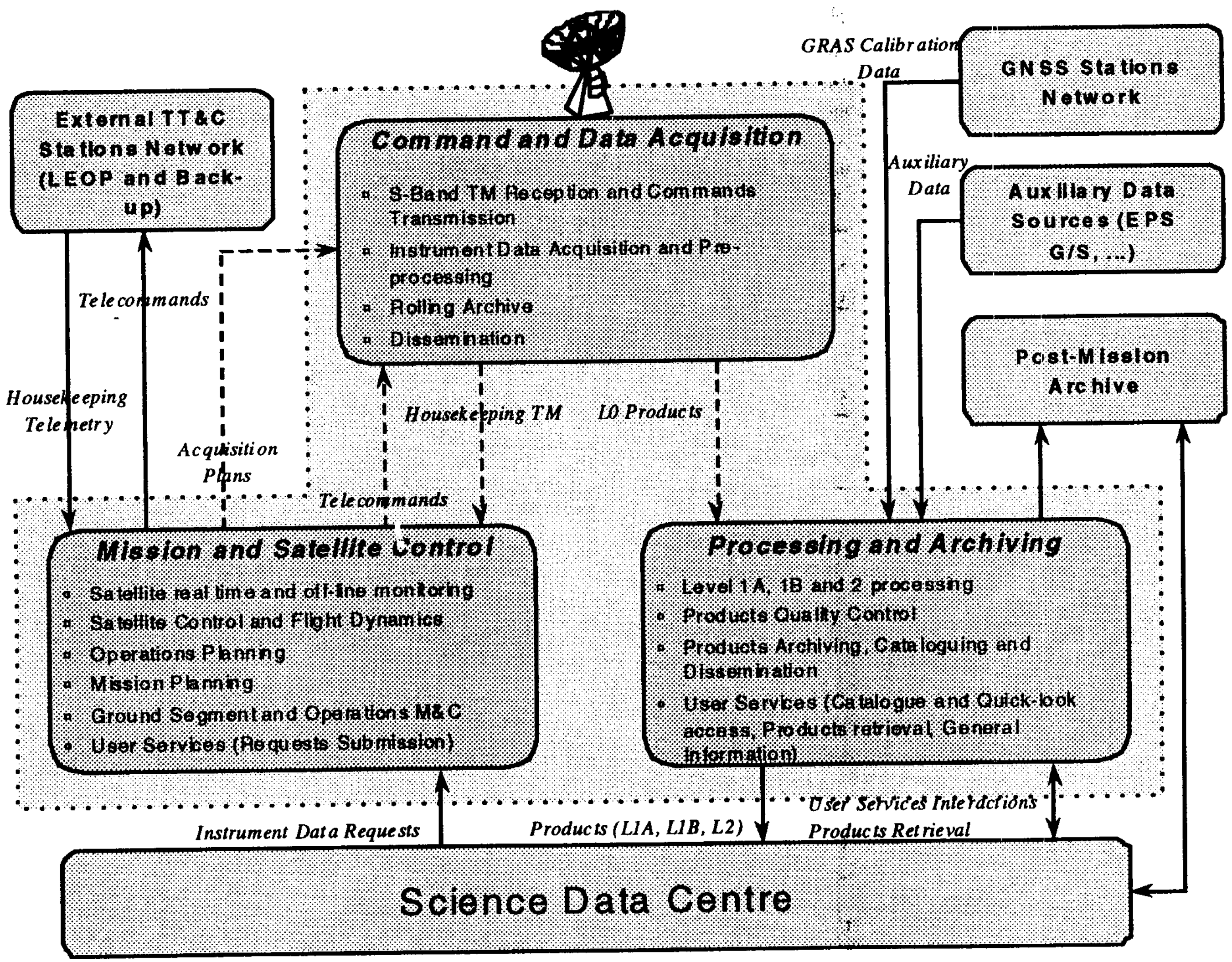


Proposal Concept : Updated Spacecraft Budgets

MASS BUDGET (kg)			POWER BUDGET (Current, W)		
ERM INSTRUMENTS		*316 kg*	*ERM INSTRUMENTS*		*490 W*
ATLID	167		ATLID	225	
CPR	127		CPR	195	
Cloud Imager	12		Cloud Imager	45	
BBR	10		BBR	25	
ERM PLATFORM		*488 kg*	*ERM PLATFORM*		*253 W*
Structure / Thermal	174		Thermal	41	
Power/ Solar array / Harness	179		Harness	10	
AOCS/ Propulsion	77		AOCS	11	
OBDH / Communications	58		OBDH	64	
			Communications	22	
ERM SATELLITE		*804 kg*	*ERM SATELLITE*		*743 W*
Contingency (20%)		161	Cont/Loss (20 %)		
PROPELLANT (2 yr life at 410 km)		35			
TOTAL SATELLITE)		***1000 kg****	***TOTAL SATELLITE***		***892 W****

* *-Proposal totals including GRAS, cooled CI and CERES BBR were 1106 kg and 1019 W*
-Launcher Capacity at 410 km is 1050 kg for Rockot and 1175 kg for Athena 2

Proposal Concept : Ground Segment Overview



ERM Programmatic Approach

- **The Cost concern**
  - ⇨ Demonstrating that the Earth Radiation Mission is achievable within the budgetary envelope of an Earth Explorer mission, is recognised by MMS as a major goal of this phase A study

- **Programmatic Approach during the Study**
  - ⇨ Cost will be a major driver in all technical trade-offs
  - ⇨ Realistic cost targets have been established for each constituent of the system
  - ⇨ Cost and schedule data will be maintained all along the study and permanently compared to these targets
  - ⇨ The design will be based on a maximum re-use of available hardware
  - ⇨ A cost effective development and procurement plan will be established
    - ➢ minimum number of models and maximum use of each model
    - ➢ minimum duration for each development phase
    - ➢ optimum management approach

Conclusions

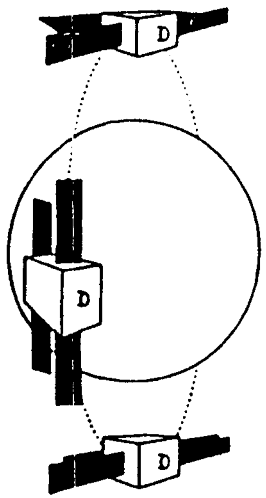
- Recent studies and technology developments related to the Earth Radiation mission / payloads and complementary assessments made by MMS within the frame of the ERM Phase A study clearly indicate that :
- **The mission is achievable with a** single spacecraft **carrying the necessary active and passive payloads**
  - ⇨ The spacecraft design (including the payloads) is **clearly feasible**, based on available hardware and demonstrated technologies. Development may start now.
  - ⇨ The spacecraft mass and power should remain **below 1000 kg and 1000 W**, which makes the spacecraft compatible with a wide set of small to medium low cost launchers
  - ⇨ The development duration (including the payloads) should remain well below 5 years, **compatible with a launch in early 2005.**
- MMS is confident in demonstrating, through this phase A, that **the development cost remains well within the cost envelope of an Earth Explorer Mission.**

Small Platforms for ROKSAR

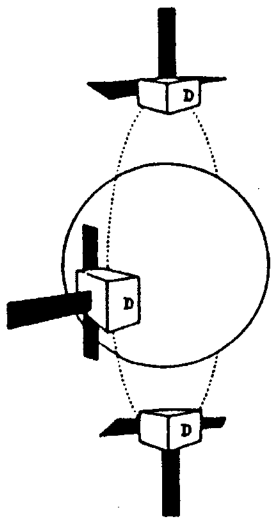
Sept 1997

SOLAR ARRAY GEOMETRY COMPARISON FOR SSOs

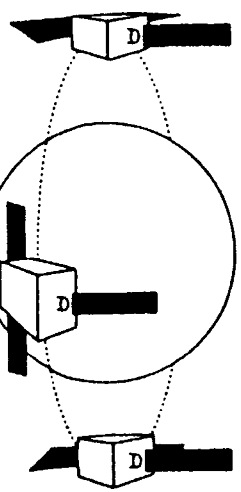
Roll
Fore and Aft Mounted



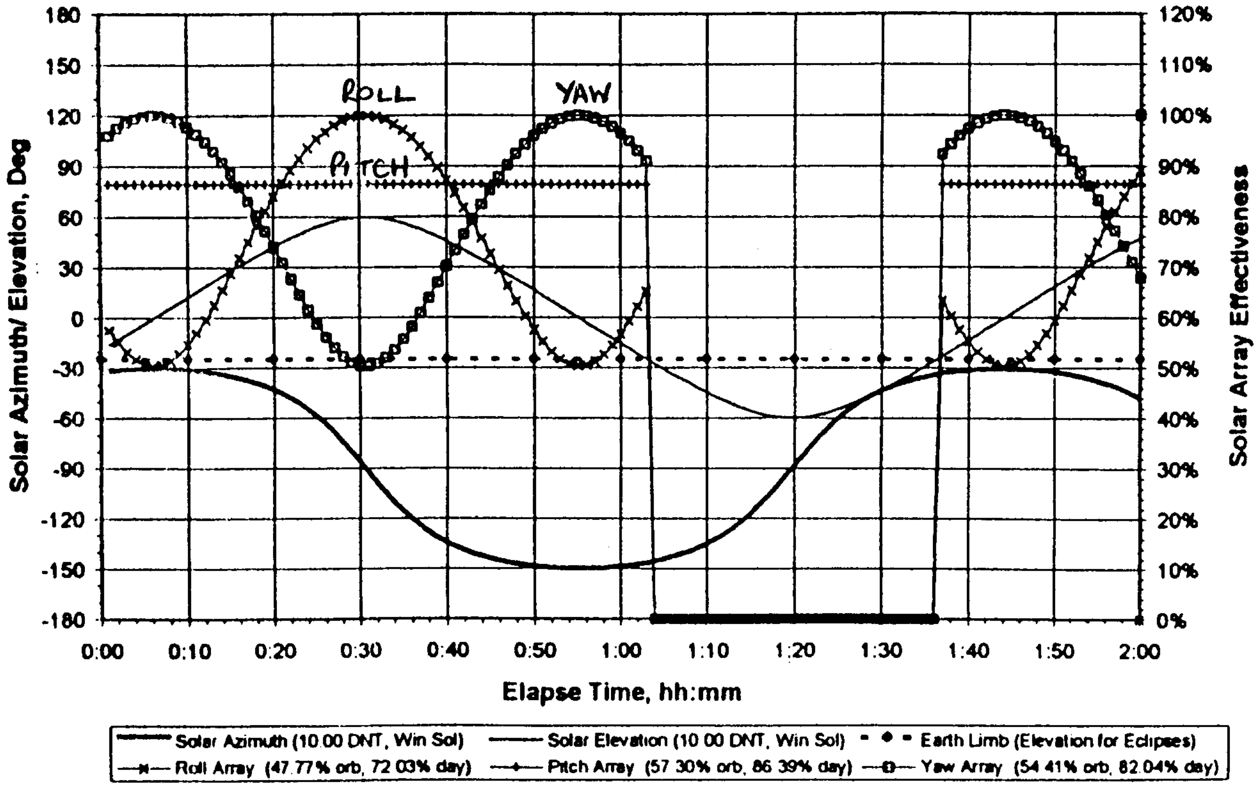
Yaw
Zenith (only)



Pitch
Left and Right



Winter Solstice : 650 km SSO, DNT = 10:00



Roksar/pres1, R.J.Flower, 15/09/97

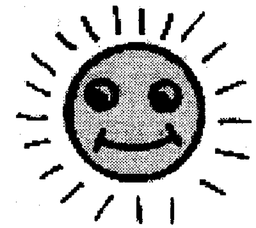
MATRA MARCONI SPACE

III. TECHNOLOGY AND SUPPORT
A. CLOUD PROFILING RADAR (CPR) CONCEPTS AND TECHNOLOGIES

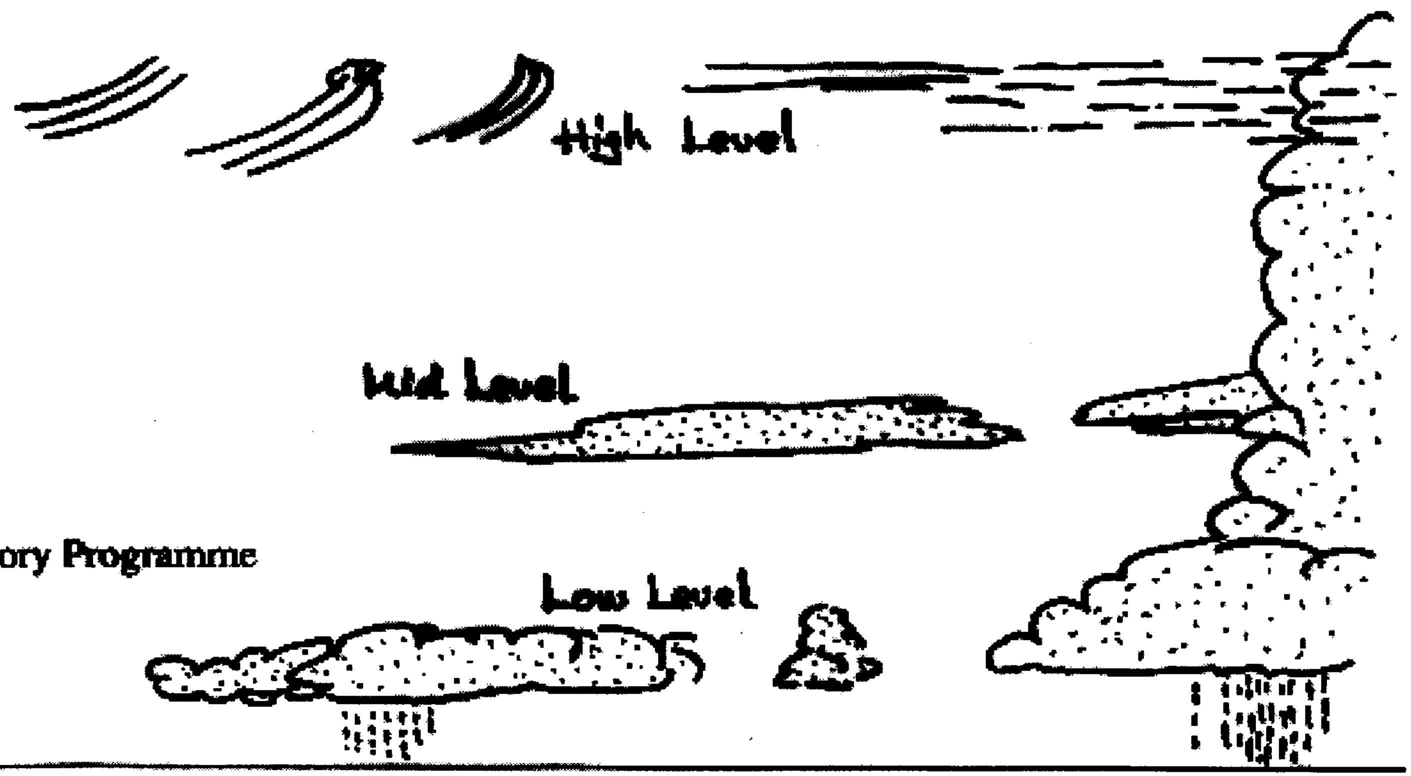
INTRODUCTION

C. C. LIN, ESA, EOPP

INTRODUCTION



Overview of Cloud Profiling Radar Activities



C.C. Lin

Earth Observation Preparatory Programme

Overview of the CPR Instrument/Technology Activities

- Instrument Preliminary Design: *Pre-phase A studies*
- Critical Technology Items: *94 GHz components/subsystems*
- Frequency Allocation: *94.0 - 94.1 GHz primary allocation obtained at WRC '97*

Instrument Studies

93 - 94: Millimeter-Wave Spaceborne Cloud Radar Feasibility Study (GS)
ESTEC Contract No. 10298/93/NL/NB to MMS-UK

96 - 97: Millimeter-Wave Cloud Profiling Radar (MACSIM) Pre-Phase A Studies
(1) ESTEC Contract No. 11751/95/NL/CN to Dornier (D)
(2) ESTEC Contract No. 11752/95/NL/CN to Alcatel (F)

97 - (98): Feasibility Study of Advanced Cloud Radar Instrument (TRP)
ESTEC Contract No. 12647/97/NL/PA(SC) to Alcatel (F)

Technology Studies

95 - 96: Preparation for the Microwave Amplifier for Cloud Radar - Extended Interaction Klystron Amplifier
ESTEC Contract No. 11440/95/NL/CN to CPI (CDN) (formerly Varian)

95 - 96: Preparation for the Microwave Amplifier for Cloud Radar - TWT Amplifier
ESTEC Contract No. 11494/95/NL/CN to Thomson TE (F)

95 - 96: Electronic Power Conditioner for a 94 GHz Klystron (Part I) and TWT (Part II)
ESTEC P/O 144217 to Dornier (D)

95 - (98): Spaceborne Cloud Radar Critical Subsystem Breadboarding (TRP)
ESTEC Contract No. 11519/95/NL/PB to Officine Galileo (I)

98 - (2000): 94 GHz Test Vehicle - Extended Interaction Klystron (GSTP + EOPP)
ESTEC Contract No. 12829/98/NL/NB to CPI (CDN)

98 - (2000): Cloud Radar LNA/Down Converter (GSTP)
ESTEC Contract No. XXXXX/98/NL/NB to Ylinen (FIN)

99 - (2000): Cloud Radar Critical Technologies - Up Conversion/Driver Amp. (TRP)

99 - (2000): Spaceborne Weather Radar Antenna (TRP)

Frequency Compatibility Study

95 - 98: Study of Protective Measures for MMW Radiotelescopes against Interferences Generated by Spaceborne Cloud Profiling Radar
ESTEC Contract No. 11704/NL/PB to Oerlikon-Contraves (I)

MACSIM Requirements Specification

Frequency:	**94.05 GHz**	⇨	sensitivity vs. attenuation
Antenna pointing:	**Fixed nadir**	⇨	spatial sampling issue
Vertical resolution:	**500 m (350 m)**	⇨	cloud top/bottom localisation
Minimum sensitivity:	≤ **-33 dBz (-30 dBz) (for 10 km integration)**		
Radiometric accuracy:	≤ **1.7 dB**		
Ground clutter:	≤ **-33 dBz**	⇨	range sidelobes control

Minimum Sensitivity $\leq$ -30 dBz

$$\eta = 10^{-6} \times \frac{\pi^5}{\lambda^4} \times |K|^2 \times z \qquad [m^{-1}]$$

: per-unit-volume scattering cross-section

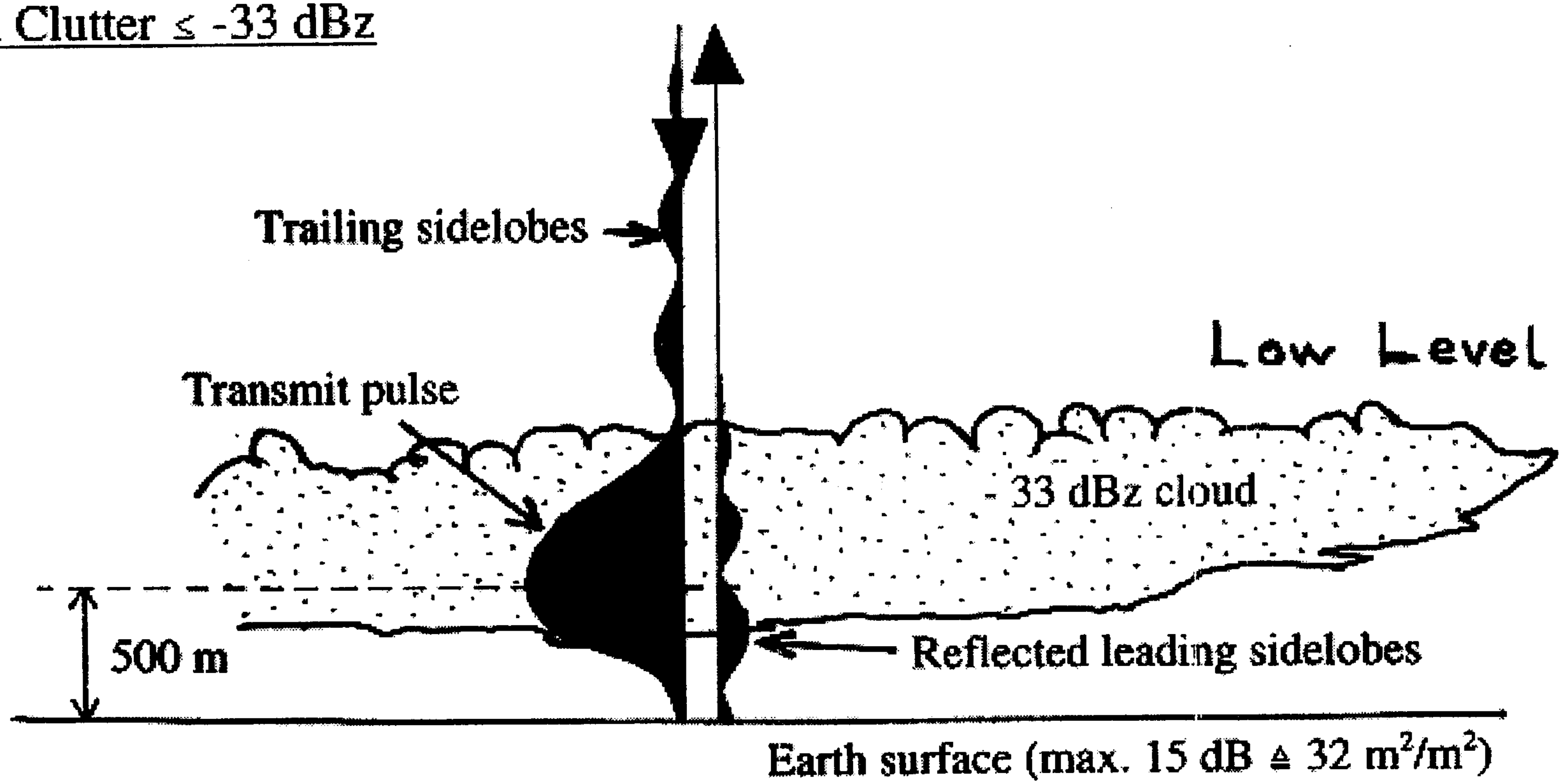
z: radar reflectivity factor

$$z = \int_0^\infty D^6 N(D) dD \qquad [mm^6 m^{-3}] \qquad \leftrightarrow \qquad Z = 10 \times \log z \qquad [dBz]$$

$$\mathbf{z \leq 10^{-3}\ mm^6 m^{-3}} \qquad \leftrightarrow \qquad \mathbf{Z \leq -30\ dBz}$$

$\triangleq$ One droplet of $\varnothing$0.32 mm per m^3 !!!!

Ground Clutter $\leq$ -33 dBz

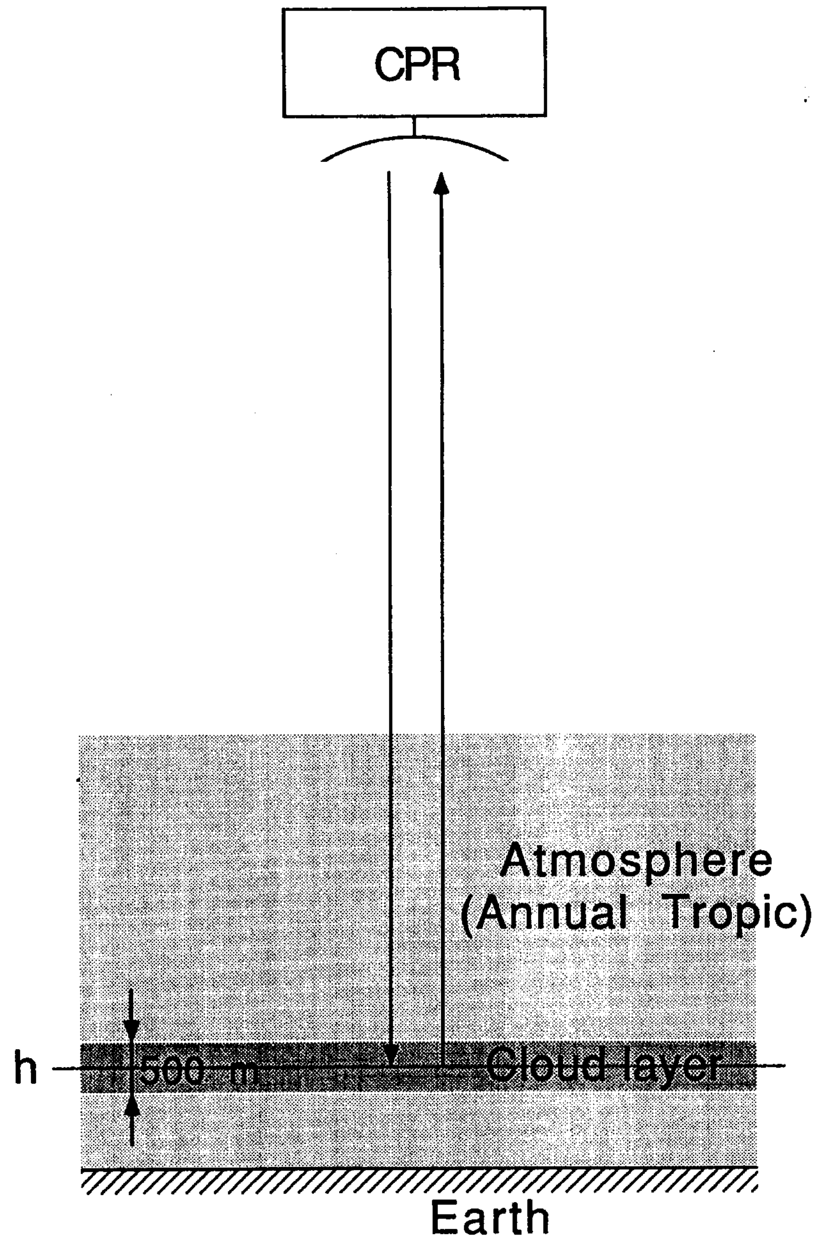


➡ Range sidelobe ratio $\geq$**80 dB** at one resolution cell distance !

PULSE COMPRESSION IS IMPOSSIBLE !

Clear Atmospheric Attenuation

Altitude [km]	One-way total zenith attenuation [dB]	
	Annual Tropic	Summer Mid-Latitude
0	**2.17**	1.45
0.25	**1.89**	1.26
0.50	**1.64**	1.10
0.75	**1.41**	0.95
1.0	**1.21**	0.83
1.5	**0.88**	0.62
2.0	**0.64**	0.47
4.0	**0.20**	0.17
6.0	**0.080**	0.076
8.0	**0.042**	0.041
12.0	**0.015**	0.014
16.0	**0.005**	0.004
20.0	**0.001**	0.001
25.0	**0.000**	0.000



Sensitivity for a single cloud layer of 500 m thickness (10 km integration)

Altitude [km]	Alcatel design	Dornier design
0.25	-32.8 dBz	-31.7 dBz
2.0	-35.9 dBz	-34.8 dBz
4.0	-37.2 dBz	-36.1 dBz
6.0	-37.5 dBz	-36.4 dBz
8.0	-37.7 dBz	-36.6 dBz
12.0	-37.8 dBz	-36.7 dBz
16.0	-37.9 dBz	-36.8 dBz
20.0	-38.0 dBz	-36.9 dBz

III. TECHNOLOGY AND SUPPORT

A. CLOUD PROFILING RADAR (CPR) CONCEPTS AND TECHNOLOGIES

CLOUD PROFILING RADAR; CONCEPT STUDY RESULTS

H. R. SCHULTE, DORNIER

Cloud Profiling Radar

Concept Study Results

Instrument Pre-phase A Study:	performed from April 1996 to July 1997
ERM Phase A Study:	kicked-off 3 rd July 1998

Dornier Satellitensysteme

Dr. H.R. Schulte, Dr. S. Riegger, U. Mallow

Table of Contents

1. Status of Requirements (extract only)

	MACSIM Pre-phase A	ERM-CPR Phase A	Comment
Mission Lifetime	4 years	2 years	Relaxation
Orbit Altitude	500 - 600 km	-	Possibly relaxed
Observed Altitude Range	0.25 to 25 km	0.5 to 20 km	Understood as centre of a sample
Along Track Integration	30 km	10 km	More stringent
Frequency	95 or 79 GHz	94.05 GHZ	
Vertical Resolution	500 m	p: 500 m; s 350 m	
On-Board averaging	1 km x 1 km	1 km x 1 km	
Absolute radiometric Acc.	< 1.7 dB	< 1.7 dB	
Cloud base Location Acc.	250 m	250 m	
Absolute vertical position	-	50 m (10 m relative to ATLID)	new requirement
Top of Dynamic Range	20 dBZ	20 dBZ	
Bottom of Dynamic Range	- 30 dBZ	p: -33 dBZ; s: -30 dBZ	More stringent
Cloud and Air Models	Specified via table	improved	relaxed
Cloud model	impossible to meet	three layer cloud model	relaxed

2. Selection of an Overall Instrument Concept

$$Z_{min} \sim \frac{1}{SNR} \cdot \frac{1}{radiometricResolution} \cdot \frac{1}{\sqrt{N_{looks}}}$$

$\frac{1}{SNR}$: Technology

$\frac{1}{radiometricResolution}$: Probability of Cloud Detection

$\frac{1}{\sqrt{N_{looks}}}$: Timing, Technology and Cloud Base Detection

$$Z_{min} = \frac{r^2 \cdot \lambda^4 \cdot L_{TX} \cdot L_{Atm}^2 \cdot L_{ant}^2 \cdot (T_{RX} + T_{ant}) \cdot const}{P_0 \cdot \tau^2 \cdot (0.5 \cdot A_e) \cdot \left(k_{p0} \cdot \sqrt{\frac{2 \cdot \Delta x \cdot L_{proc} \cdot x_{int} \cdot PRF}{c \cdot \tau \cdot v_{gnd}}} - 1\right)}$$

$$const = \frac{8\pi \cdot k}{c \cdot |K|^2 \cdot 10^{-18}}$$

τ: transmit pulse length,
Δx_i: on ground integration length
Δx: vertical resolution
v_{gnd}: ground track velocity of the satellite
P_o: transmitter peak power
A_e: antenna "taper" effective area
r: radar range to the bottom cell
L_{atm}: clear atmospheric one way loss
L_{TX}: losses from HPA output to ant. feed
L_{ant}: losses in antenna system incl. ohmic and spillover
c: velocity of light
τ: pulse length
K: water dielectric constant
Z: cloud reflectivity
λ: wavelength
k: Boltzmanns constant
T_{RX}: eff. RX noise temp. at antenna interface (including receive path losses)
T_{ant}: eff. scene temp. at antenna

2. Selection of an Overall Instrument Concept (2)

Z_{min} $\sim PRF^{-0.5}$ ➾ Pulse repetition (number of look) should ↗

⇨ Dual frequency unmodulated pulse system

$\sim r^2$ ➾ orbit altitude should ↘

⇨ System recommendation to low orbit altitudes

$\sim 1/P_o$ ➾ Peak pulse power should ↗

⇨ Pulse compression systems

however sidelobe requirements on the pulse-compression needed to reject ground clutter lead to severe processing losses and to subsystem performance parameters nearly impossible to meet, furthermore significant range-Doppler coupling introduces additional constraints (e.g. off-nadir geometry)

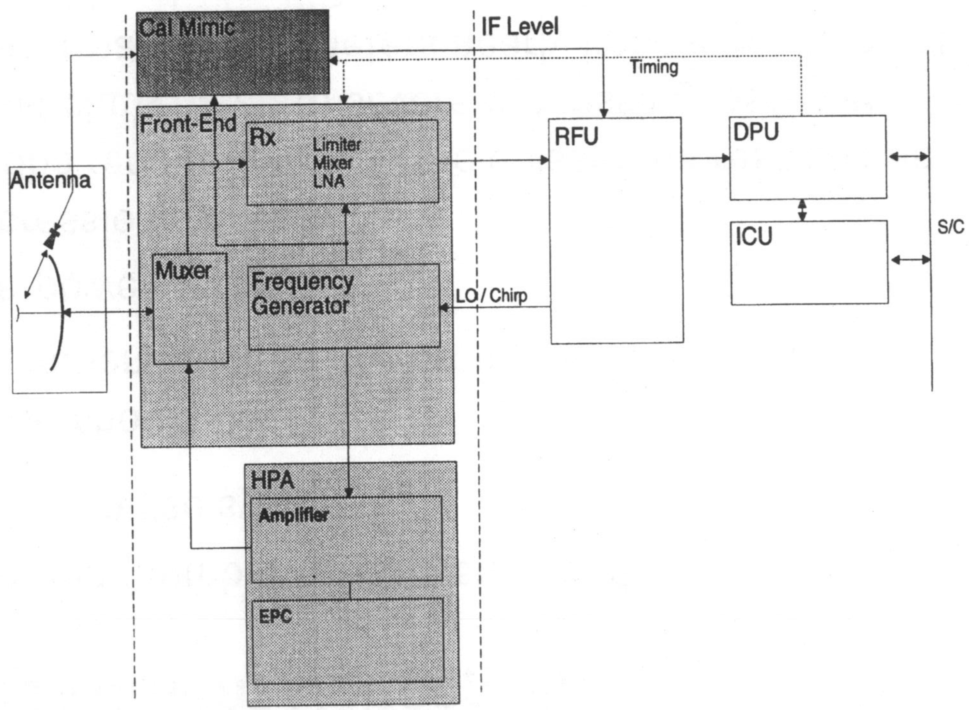
$\sim t^{-3/2}$ ➾ determined by vertical resolution. Sensitivity improved by ↗

In order to define a simple and low cost CPR the single frequency unmodulated pulse system is selected.

3. Instrument Architecture

Cloud Profiling Radar (preliminary)

Type:	unmodulated single frequency pulse system
Geometry:	Nadir looking
PRF:	Adapted to the orbit altitude
HPA Power:	about 1.5 KW
Primary Power Demand:	195 W
Mass:	about 130 kg
Data Rate:	29.7 kbps
Antenna Diameter:	1.5 - 2.5 m



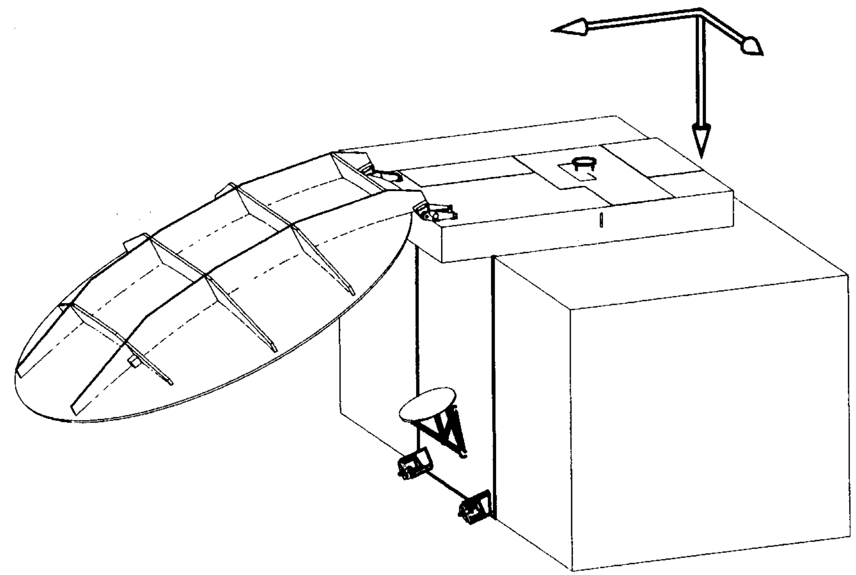
4. Antenna Reflector System

Constraints

- Footprint
- (Aperture size)

Findings

- Gaussian illumination function
- Surface error ≈ 300 μm [rms]
- L_{ant} = 0.29 dB
- T_{ant} = 290 K



Reflector Concept Alternatives

- Front-fed parabolic reflector
- Front-fed Cassegrain reflector
- Off-fed parabolic
- Dual-offset Cassegrain

Dual-offset is selected because of

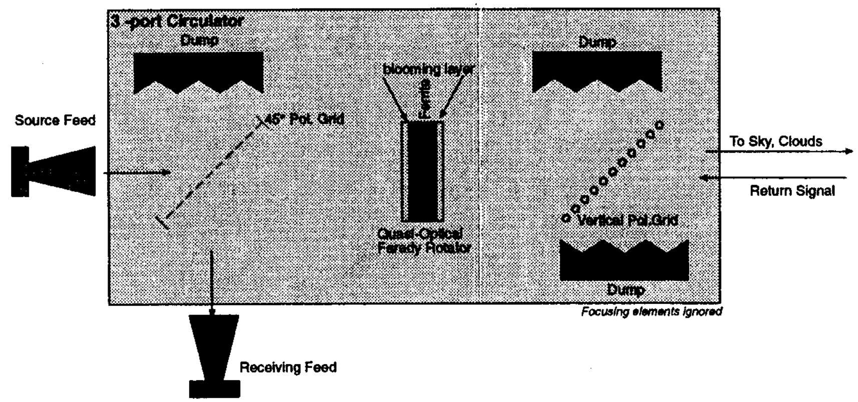
✓ highest performance
✓ optimum location of all RF equipment
✓ minor impact on manufacturing costs

5. Multiplexer: Quasi-Optical System versus Waveguide System

Functions/Requirements

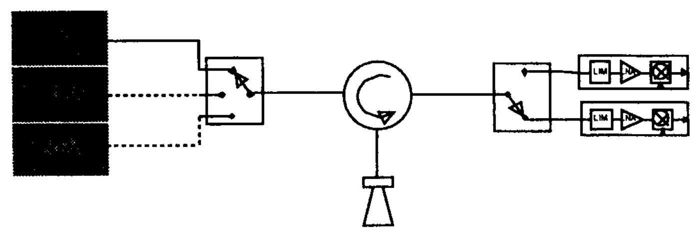
- Combination of receive and transmit channel to enable use of a single antenna for both channels
- $P_{peak} \approx 1.5$ kW
- $P_{mean} \approx 50$ W
- Isolation > 30 dB

Quasi Optics



Waveguide	Quasi-Optics
• H/W availability difficult e.g. circulators at 94 Ghz and 1.5 kW peak power • Waveguide losses • limited distance between HPA and LNA (to be cooled) • LTX ≈ 3.5 dB • LRX ≈ 1.9 dB	• Faraday rotator enables decoupling • Thermal load on Faraday rotator • Accommodation flexibility for LNA • Cloud reflection maintains polarisation • $L_{RX} = L_{TX} \approx 0.83$ dB

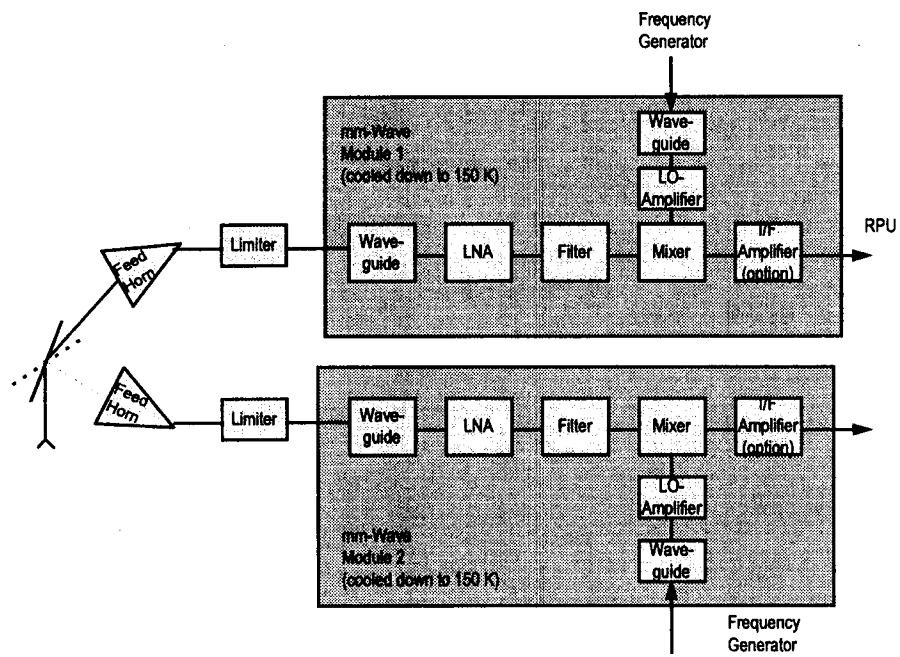
Waveguide



6. Receiver

Functional Requirements

- Coupling in of RF signals
- Input stage power protection (T_X signal)
- Amplification of received signal
- Signal down conversion (≈ 9 GHz)
- LO conditioning



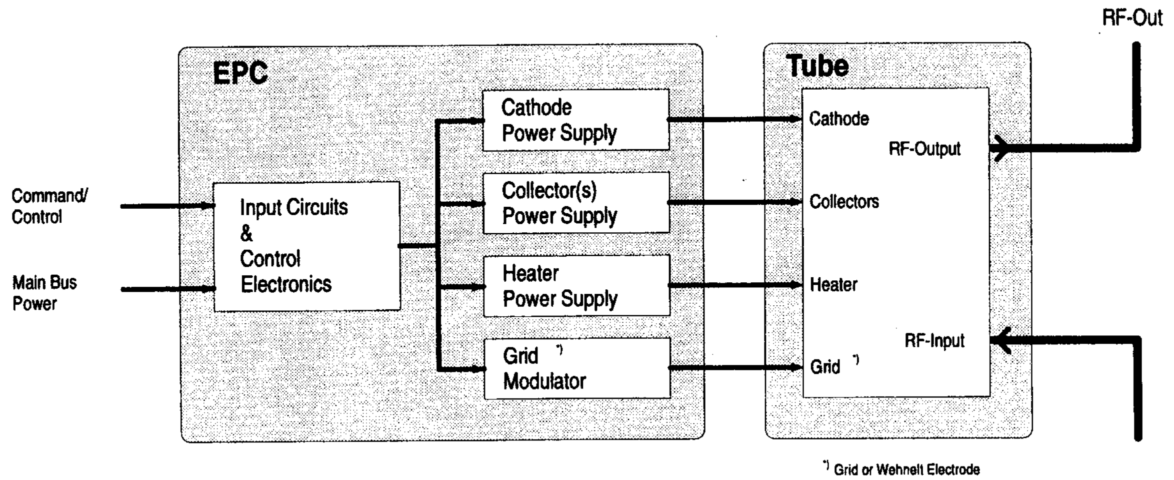
Issues

- Losses are high (with today products)
- Number of products available is limited because of a limited market
- Cooling of LNA could provide improvement of up to 2 dBZ

7. Transmitter

Functional Requirements

- Amplification of RF transmit signal
- Low interpulse noise
- Conditioning of power supply



Selection Criteria

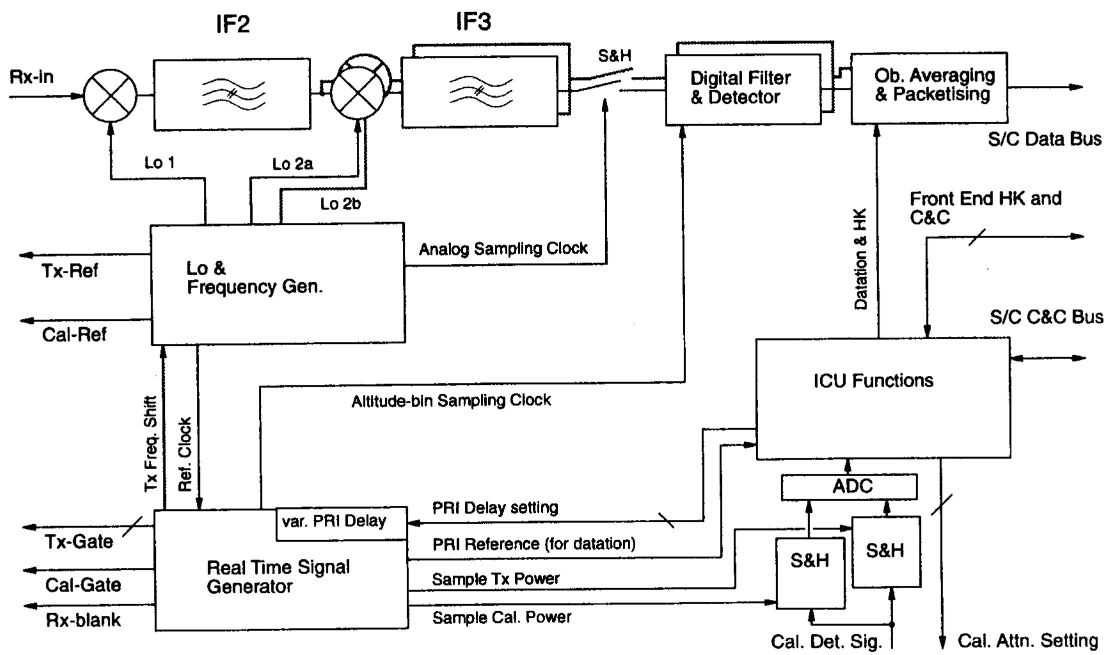
- High peak power output
- Frequency range
- Lifetime (≈ 20000 h)
- Availability

EIK	TWT	EPC
• Available Klystron for terrestrial applications • some improvements needed to reach - higher efficiency - longer lifetime - thermal environment	• available design principles for space applications • lower cathode current (6 A/cm2) but higher cathode voltage (-35 kV) • difficulties w.r.t. accommodation	• Existing design *), however some modifications needed • Grid/Wehnelt control with - high voltage swing (2.1 kV) - high beam-on voltage accuracy (±2 V) - short rise time (100 ns) *) mass reduction possible with new design

8. Support Functions and Processing

Main Functions/ Requirements

- Signal conversion, filtering, detection, digitalisation and integration
- Provision of oscillator signals, clock and timing
- Interface with S/C
- Minimisation of processing losses



Alternative Signal Processing Concepts

- Employing a filter derived from low-pass filter
- Employing a filter derived from a matched filter

9. Performance Predictions

= cloud profiling radar

Earth Radiation mission

Requirement	(ERM)	Characteristics	MACSIM	ERM-CPR
Vertical resolution				
• primary	500 m	Pulse length 3.34 μs	500 m	500 m
• secondary	350 m	Pulse length 2.33 μs		350 m
Horizontal resolution	1 km x 1 km	Antenna dia. 2.5 m	1 km x 0.78 km	1 km x 0.78 km
Abs. rad. accuracy	1.7 dB		1.4 dB	1.43 dB
Top dyn. range	20 dBZ	Po = 1.5 kW	27.5 dBZ	27.5 dBZ
Bottom dyn. range		LNA temp. 150 K		
• primary	- 33 dBZ	Orbit altitude 500 km	- 34.06 dBZ 1)	- 32.76 dBZ
• secondary	- 30 dBZ			- 29.76 dBZ
Cloud base location	250 m		165 m	n/c
PRF min		(change due to observation range change)	4281 Hz	6278 Hz
PRF max			4511 Hz	6615 Hz

1) without cloud model attenuation and at 30 km integration distance

III. TECHNOLOGY AND SUPPORT
A. CLOUD PROFILING RADAR (CPR)
CONCEPTS AND TECHNOLOGIES

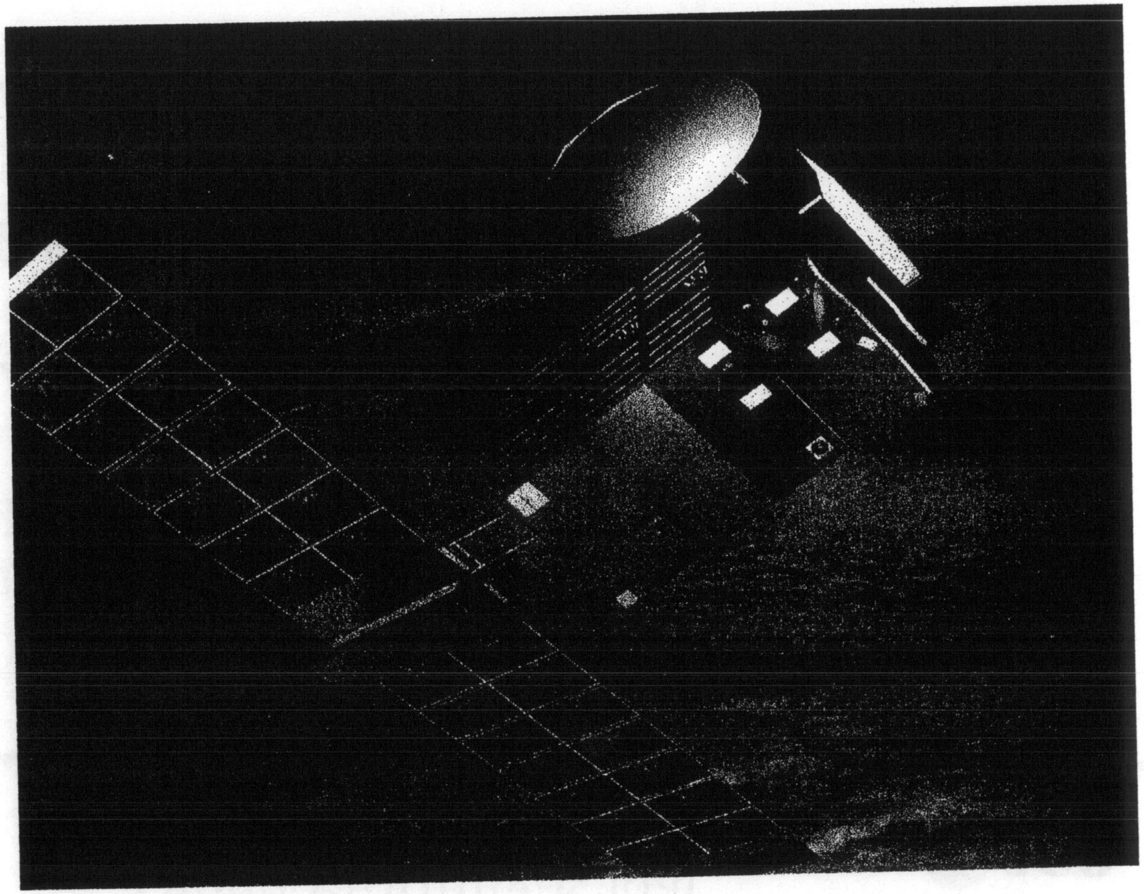
CLOUD PROFILING RADAR CONCEPT STUDY

I. PHALIPPOU, ALCATEL

Cloud Profiling Radar
concept study

MACSIM

Millimeter Active Cloud Structure Imaging Mission



CONTEXT

Results of a pre-phase A study funded by ESA and led by ALCATEL ESPACE with five other European companies :

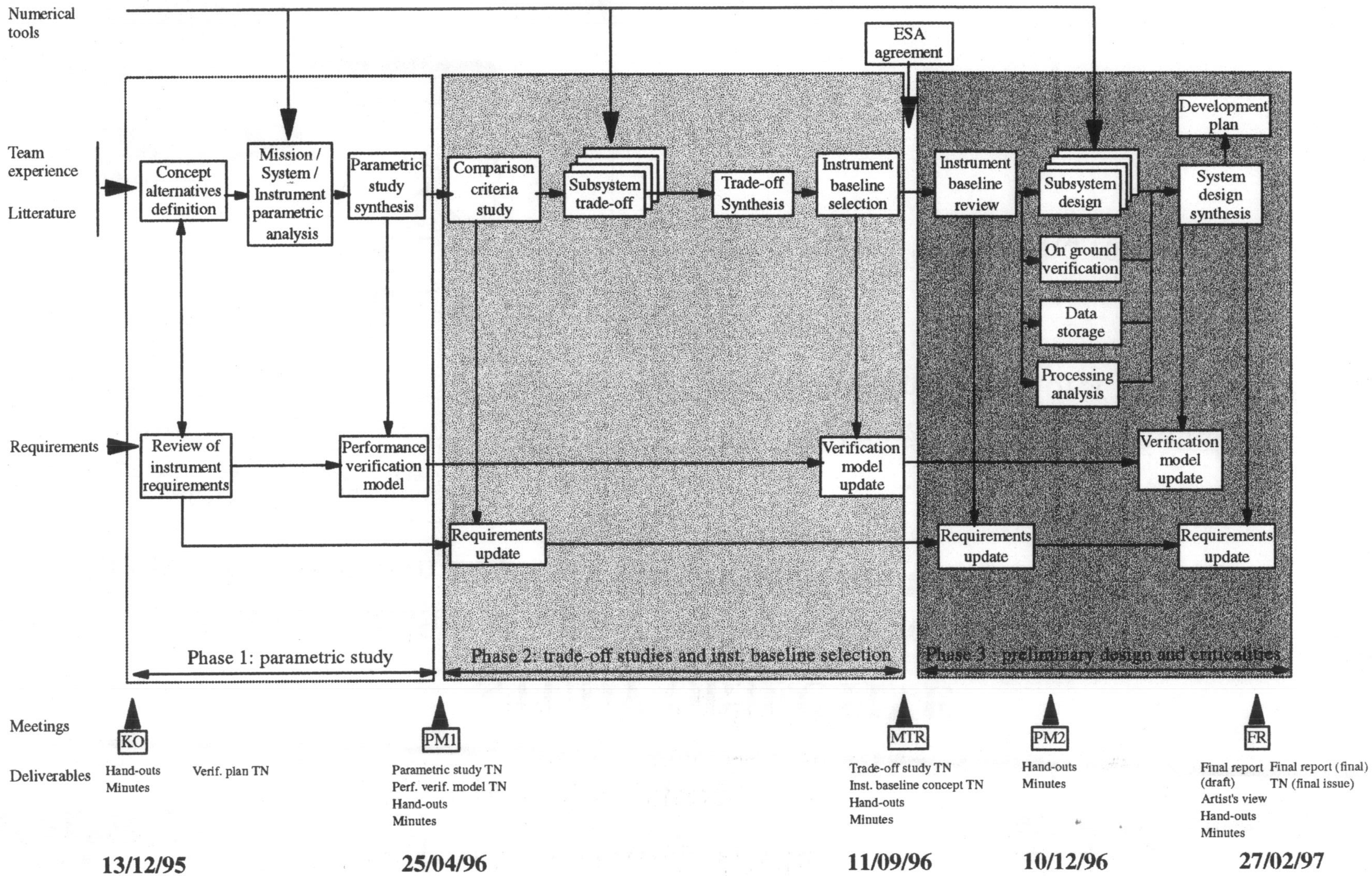
- ◊ ALCATEL ESPACE (France) for system part
- ◊ CETP (France) for expertise on mission analysis
- ◊ CASA (Spain) for antenna s/s and RF distribution
- ◊ SAAB ERICSSON SPACE (Sweden) for Digital Electronics s/s
- ◊ OERLIKON CONTRAVES (Italy) for RF s/s & EPC of HPA s/s
- ◊ CPI (Canada) for HPA s/s (tube alternative)

ALCATEL

Cloud Profiling Radar concept study

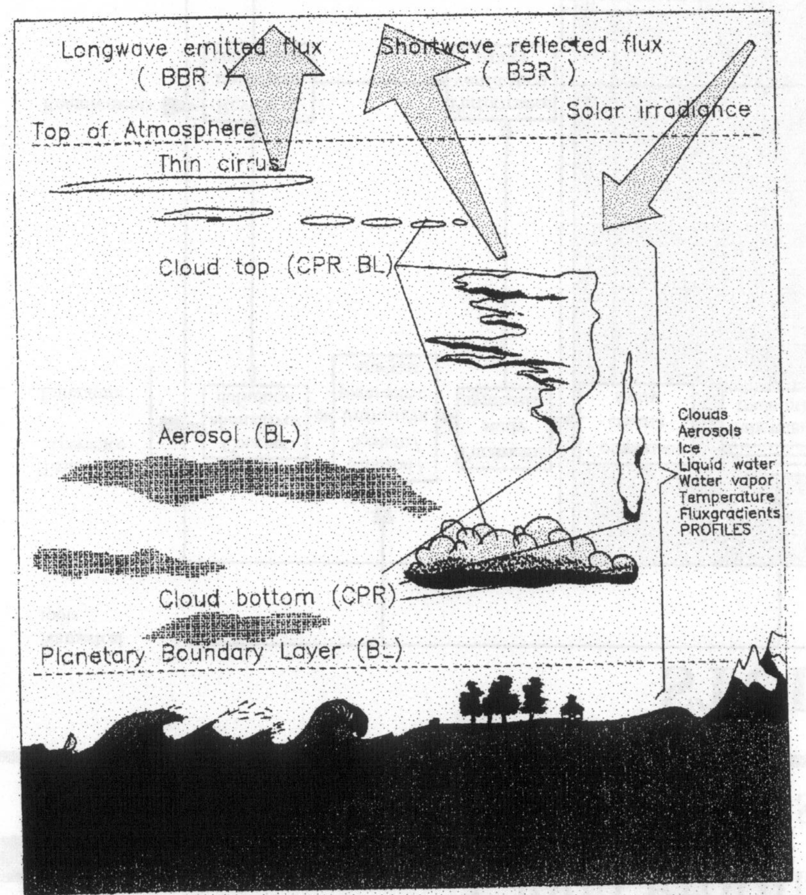
esa

STUDY LOGIC



STUDY OBJECTIVE

Definition of a preliminary design of a fixed looking spaceborne cloud radar, one of the two main instruments of ESA Earth Explorer Radiation Mission.



Schematic of observational requirements of Earth Explorer Radiation Mission

BBR = broadband radiometer

BL = backscatter lidar

CPR = cloud profiling radar

Main instrument requirements

◊ Satellite altitude : between 500 and 600 km

◊ Radar frequency : 95 of 79 GHz (W-band)

◊ Observation window : 0.25 km (des.) - 0.75 km (acc.) to 25 km

◊ Cloud detection : -30 dBZ to +20 dBZ

◊ Vertical resolution : 250 m (des.) to 500 m (acc.)

◊ Footprint resolution : lower than 1 km

◊ Total radiometric accuracy : lower than 1.7 dB (integration distance of 30 km)

◊ Localisation accuracy of cloud base altitude : lower than ± 250 m

◊ Instruments interfaces : mass lower than 250 kg and
power consumption lower than 250 W

INSTRUMENT CONCEPT

◊ Transmission of an unmodulated pulse (CW pulse)

➡ width proportionnal to vertical resolution

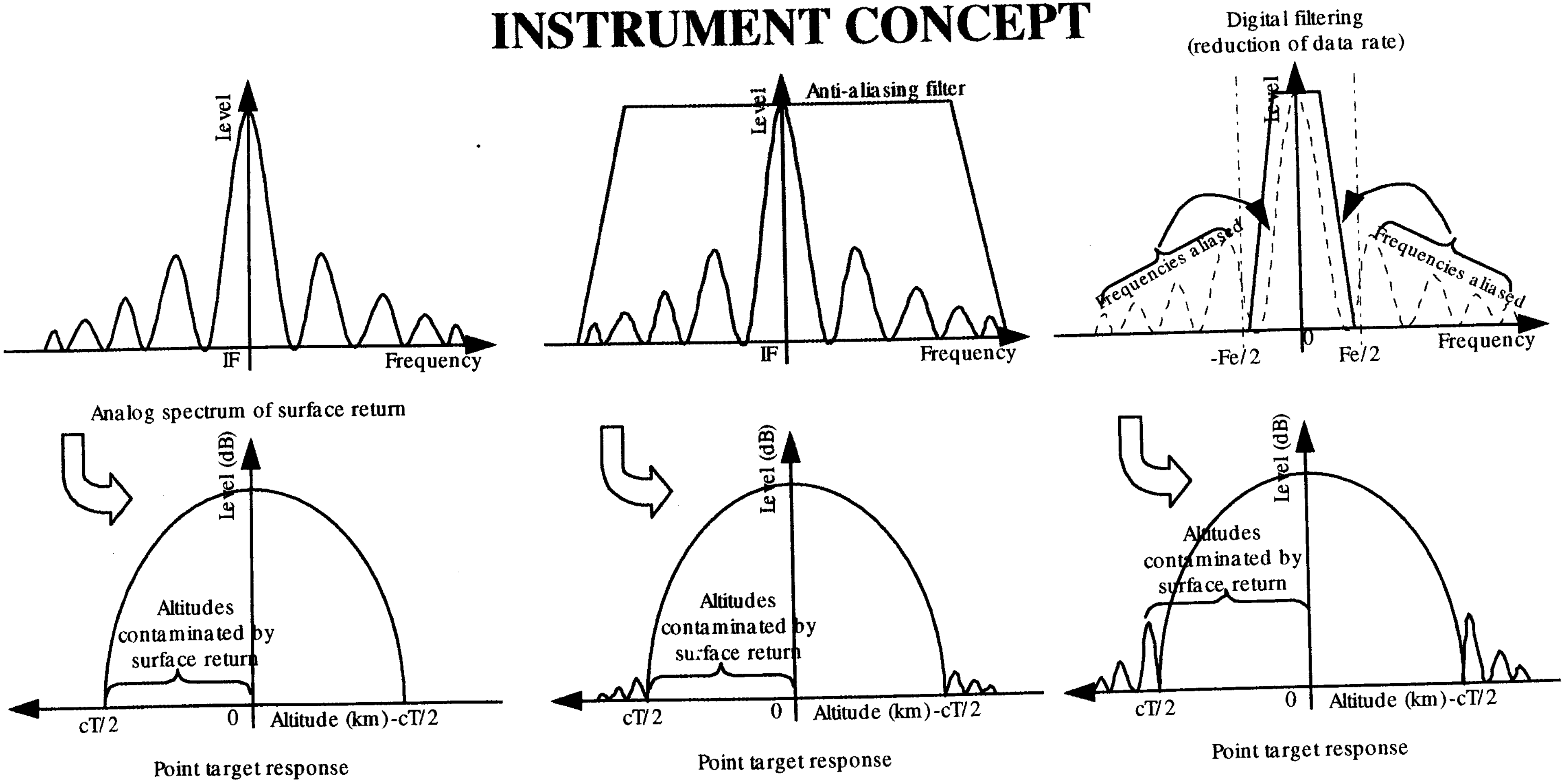
◊ No pulse compression technique is implemented due to the too high contamination of the weak cloud echoes through the sidelobes of the compressed surface return.

◊ Pulse duration ~ 3.33 μs

◊ Matched filtering of received echoes

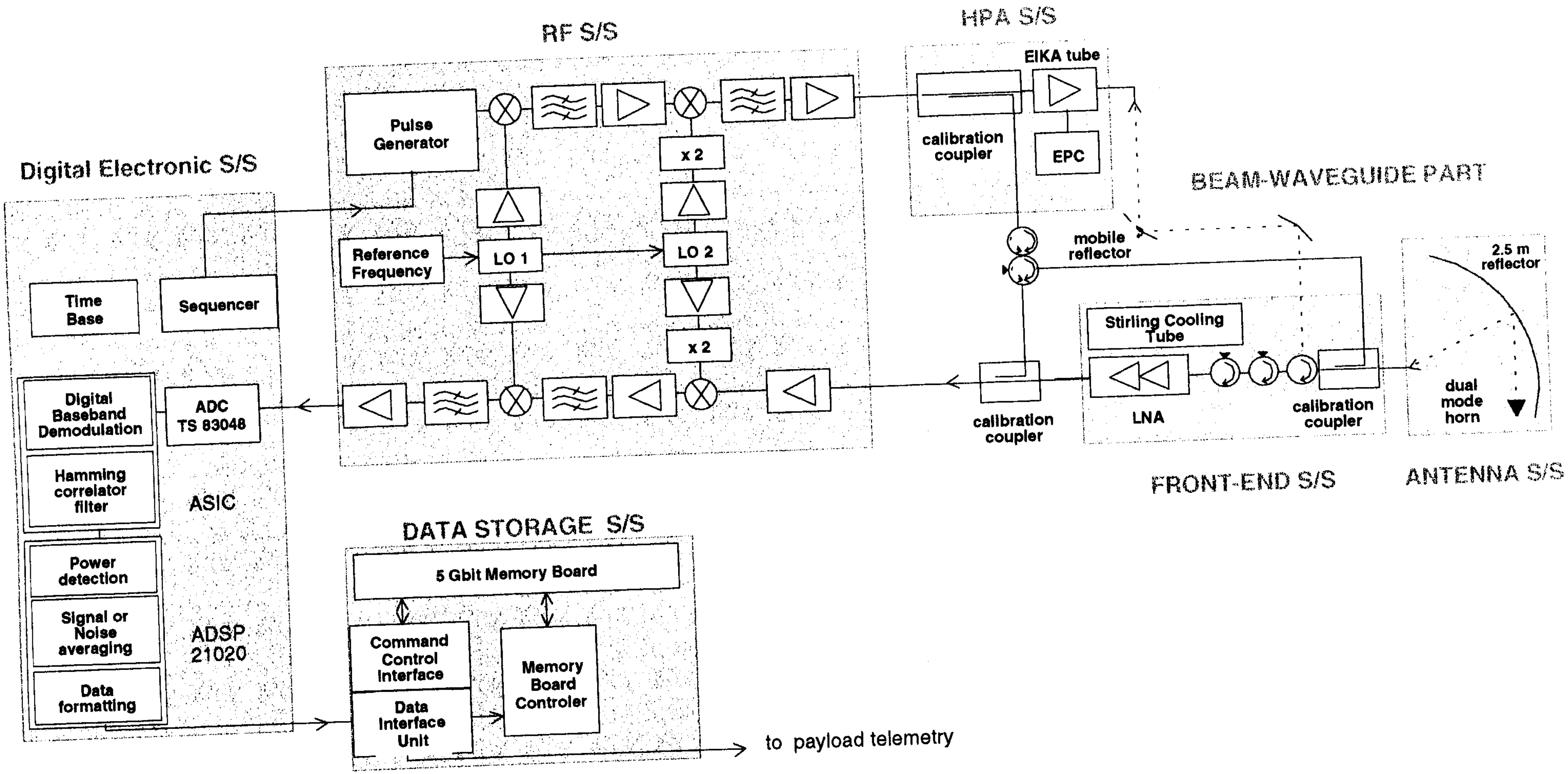
➡ thermal noise filtering
➡ theoretical PTR width = twice pulse width
➡ pulse width ≤ blind layer

INSTRUMENT CONCEPT



➡ degradation of the minimum detectable cloud altitude (blind layer)

MACSIM INSTRUMENT BLOCK DIAGRAM



DIGITAL SUBSYSTEM

◊ Pulse control unit

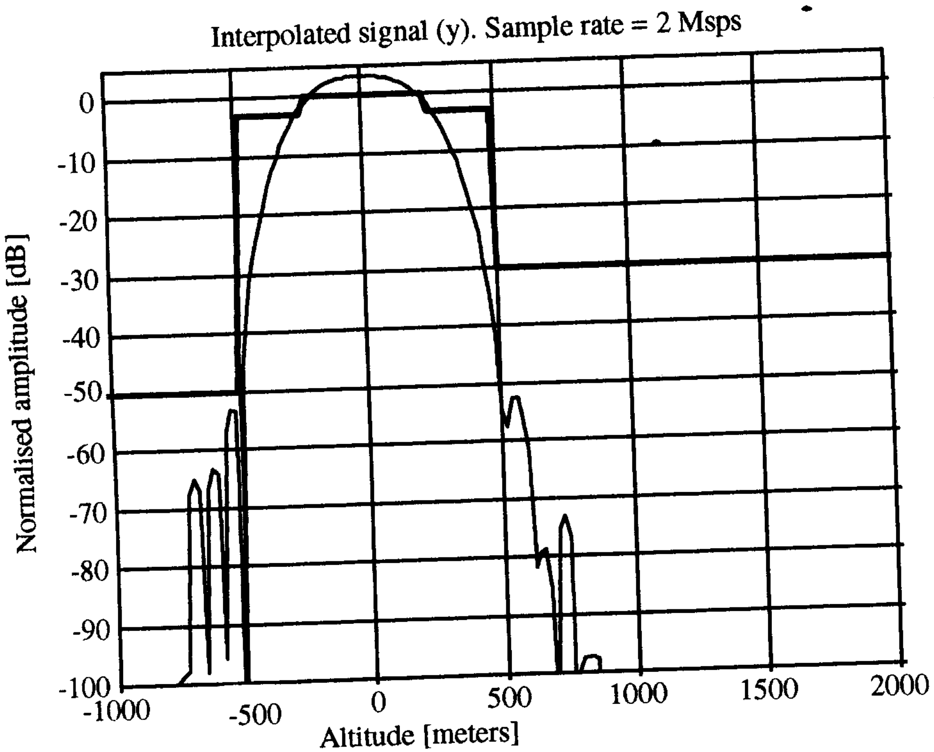
◊ ADC & digital amplitude phase demodulation

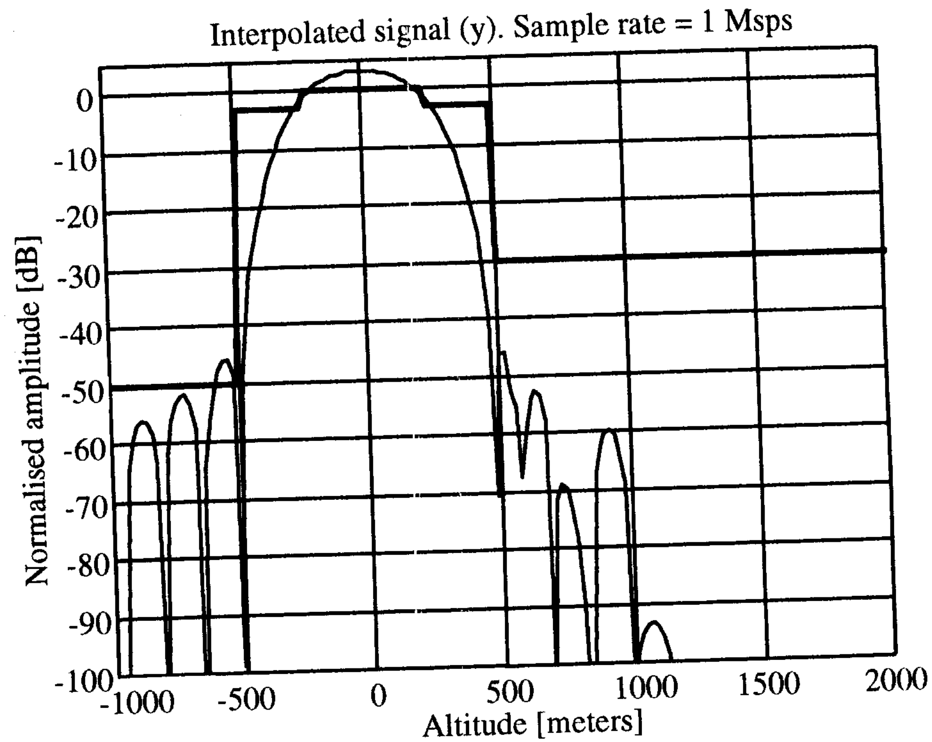
◊ Processing unit (pulse correlation + detection + averaging)

- signal acquisition window 170 μs
- signal acquisition frequency 4.4 kHz
- noise acquisition window 20 μs before signal acquisition
- correlation filter with Hamming window
- averaging time 0.14 s (1 km)
- output data rate 2.0 MHz

◊ Sequencer

DIGITAL SUBSYSTEM





Resampled correlated pulse response for Hamming window Tp = 3.33 µs.
Simulated input amplitude is according to a reflectivity of +50 dBZ and normalised to +20 dBZ (receiver chain and the ADC is driven in saturation mode)

RF SUBSYSTEM

◊ Reception of control signal from DE s/s for pulse generation (IF of 8 MHz - pulse duration of 3.33 µs)

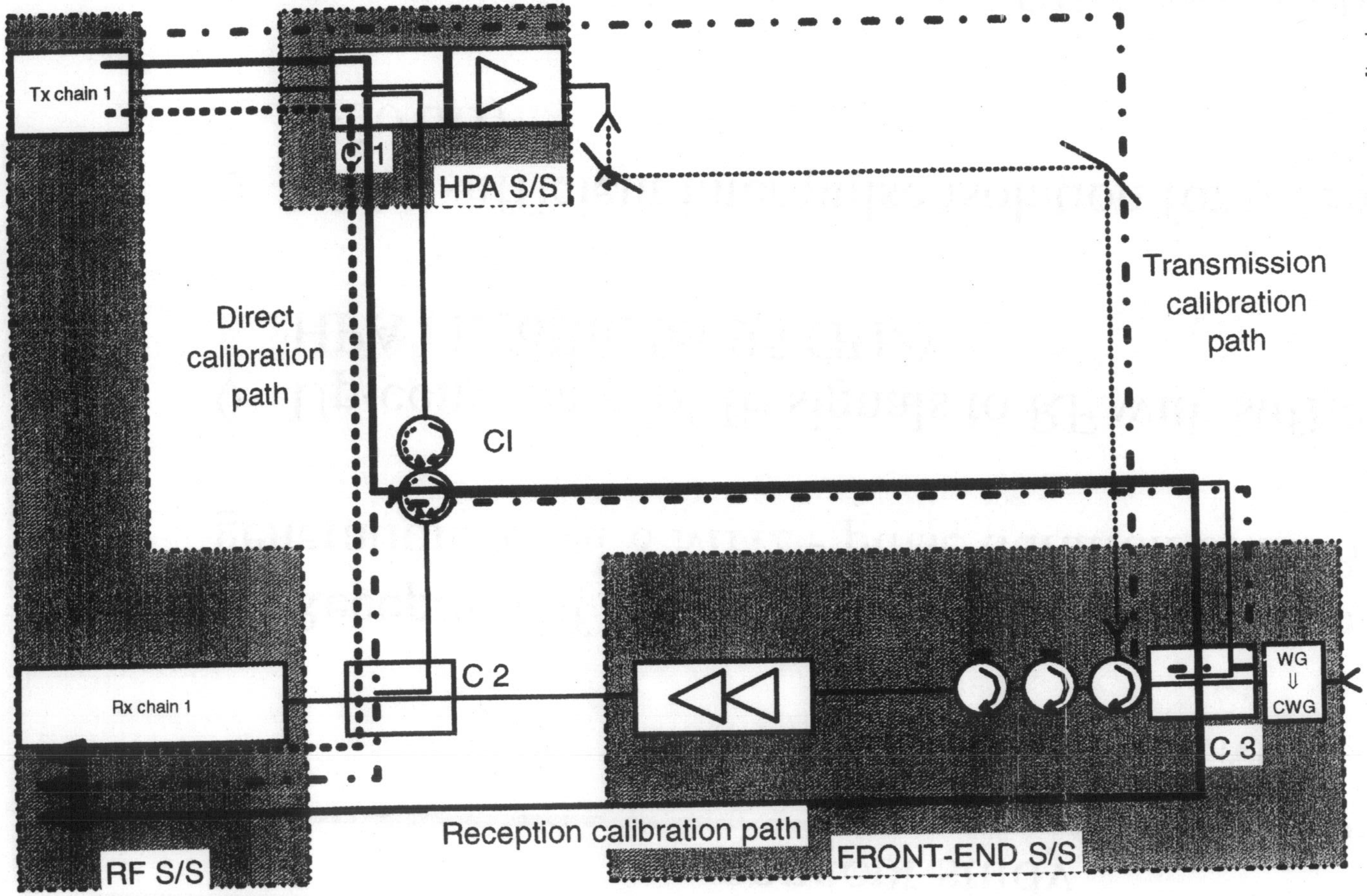
◊ Up-conversion of IF signals to RF with sufficient power for HPA (15 dBm for 95 GHz)

◊ Make sufficient inter pulse isolation for reception protection (~50 dB)

◊ Down-conversion of received RF echoes to IF

◊ Creation of a synchronous frequency for RF and DE s/s (32 MHz)

INTERNAL CALIBRATION PRINCIPLE



Measured power

P1 : Direct calibration path

P2 : Tx calibration path

P3 : Rx calibration path

$$\frac{P2\,.\,P3}{P1} = \alpha.P_{Tx}.G_{Rx}$$

➡ Internal calibration accuracy depends on couplers stability (0.3 dB expected)

HPA SUBSYSTEM

- *Amplification of RF signals from RF s/s*

◊ 1.7 kW output peak power at 95 GHz (existing EIK from CPI)

◊ 1.9 kW output peak power at 79 GHz (has to be scaled from existing EIK at 95 GHz)

◊ Critical point is cathode lifetime : 4 tubes required for a 4 year mission with sufficient reliability

◊ 15%-17% efficiency (~20-25% for tube with depressed collector)

FRONT-END SUBSYSTEM

◊ Low Noise Amplification of RF echoes

- LNA noise figure : 4.0 dB (95 GHz without cooled)
  2.5 dB (95 GHz cooled at 150 K by a Stirling Tube)
  3.5 dB (79 GHz without cooler)
  2.3 dB (79 GHz cooled at 150 K by a Stirling Tube)

◊ Receiver isolation from transmit chain power leakages

- Two ferrite isolators (0.5 dB losses)

◊ Connexion to calibration s/s

◊ Redundancy switching for LNA

HIGH POWER RF DISTRIBUTION

At the HPA output, the high level signal is distributed with a Beam Waveguide device based upon reflectors and horns

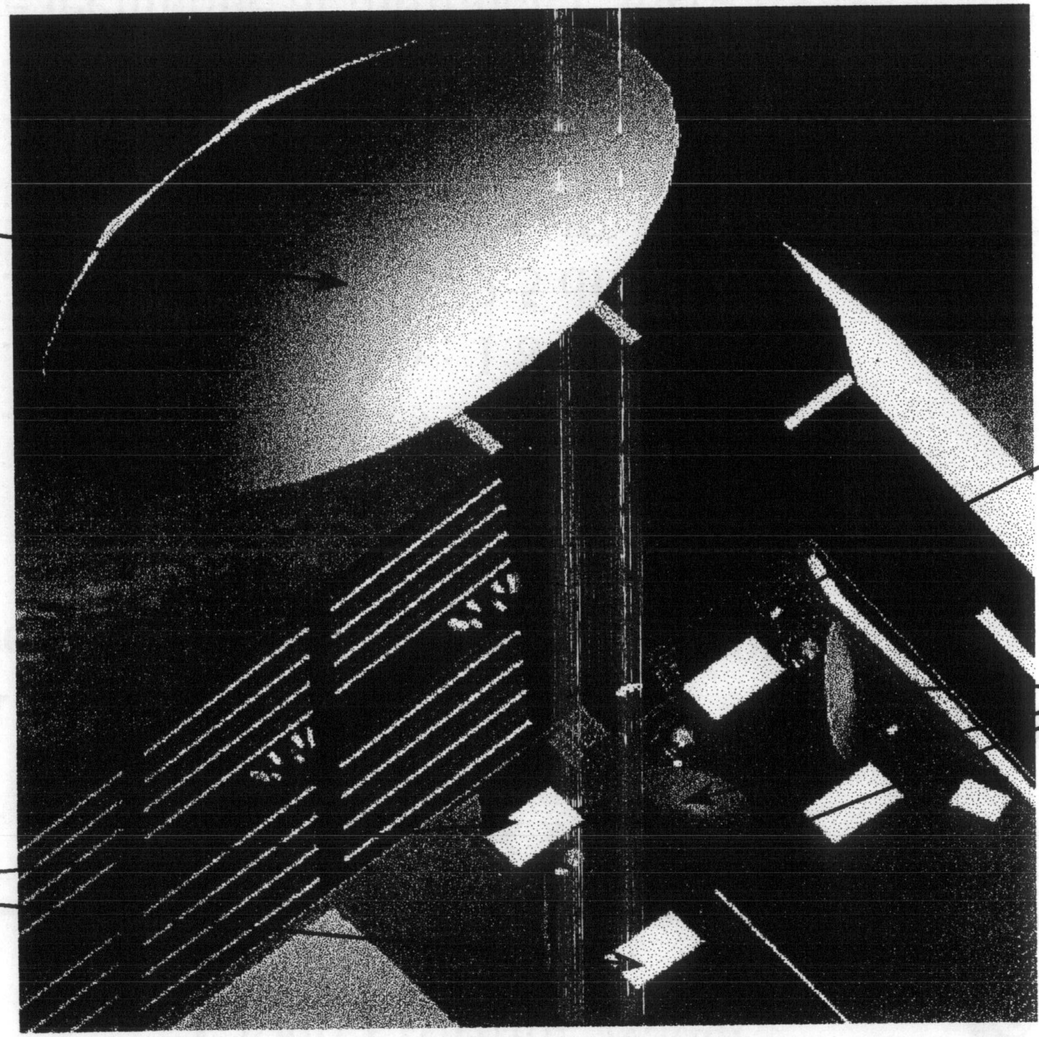
➡ reduction of transmission losses :

- BWG : 0.6 dB (95 and 79 GHz)
- WR10 (95 GHz) : 1.8 dB/m
- WR12 (79 GHz) : 2.5 dB/m
- Cylindrical WG : 0.1 dB + 0.5 dB/m + 0.15n dB (95 GHz)
- Cylindrical WG : 0.1 dB + 0.67 dB/m + 0.15n dB (95 GHz)

➡ innovative technique at millimeter-wave frequencies

➡ interesting for tube redundancy (rotating reflectors directly replace redundancy switches)

BEAM WAVEGUIDE IMPLEMENTATION



CRITICAL AREAS

◊ DE and RF subsystems : no particular risks

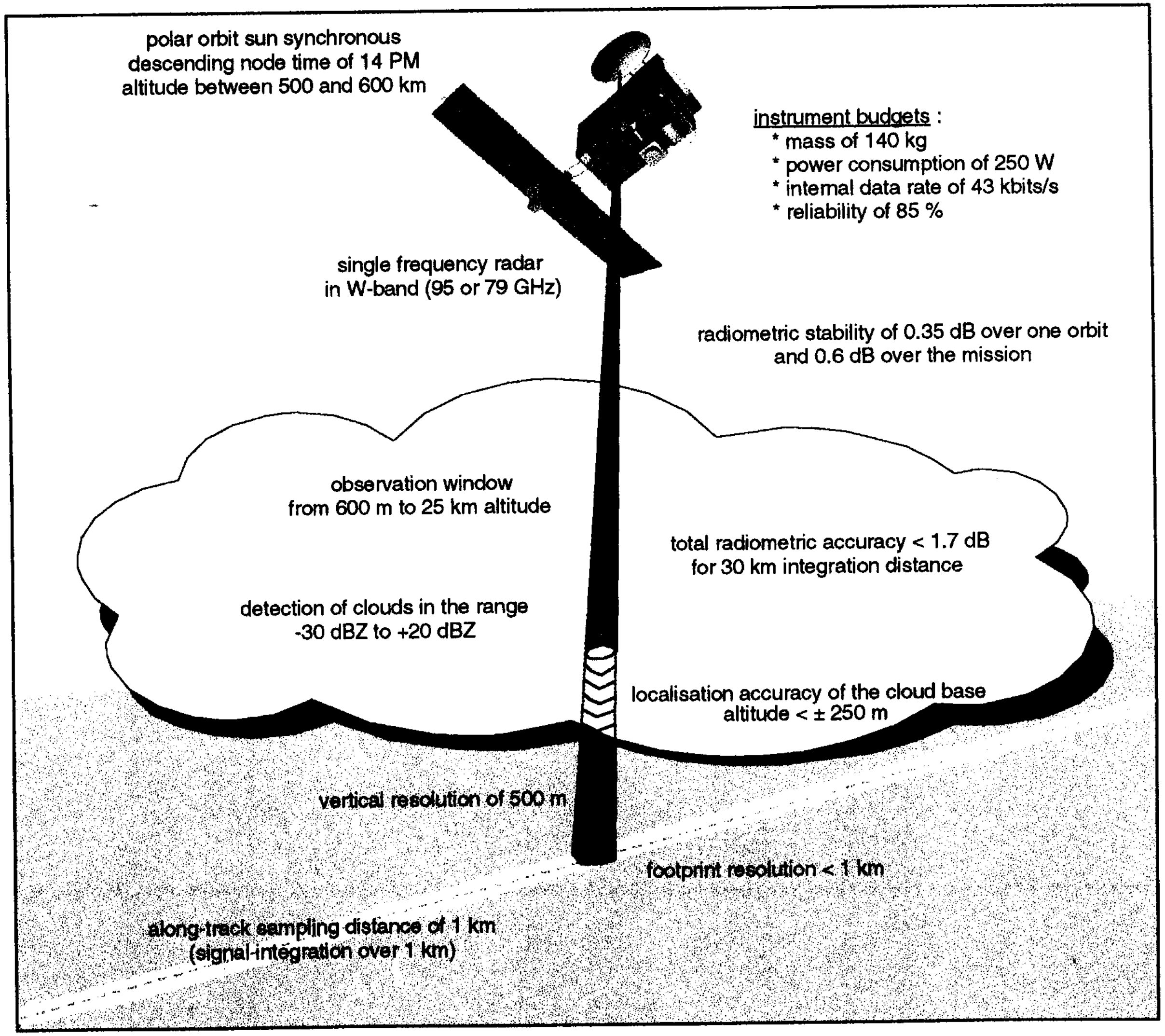
◊ Front-end subsystem : LNA performances with cooling
(On-going ESA study)

◊ HPA s/s : cathode lifetime (4 EIKA's required)

◊ Antenna and RF distribution subsystem

- BWG misalignements
- Reflector surface accuracy
- Corrugated horn at 94 GHz

MACSIM performances and budgets

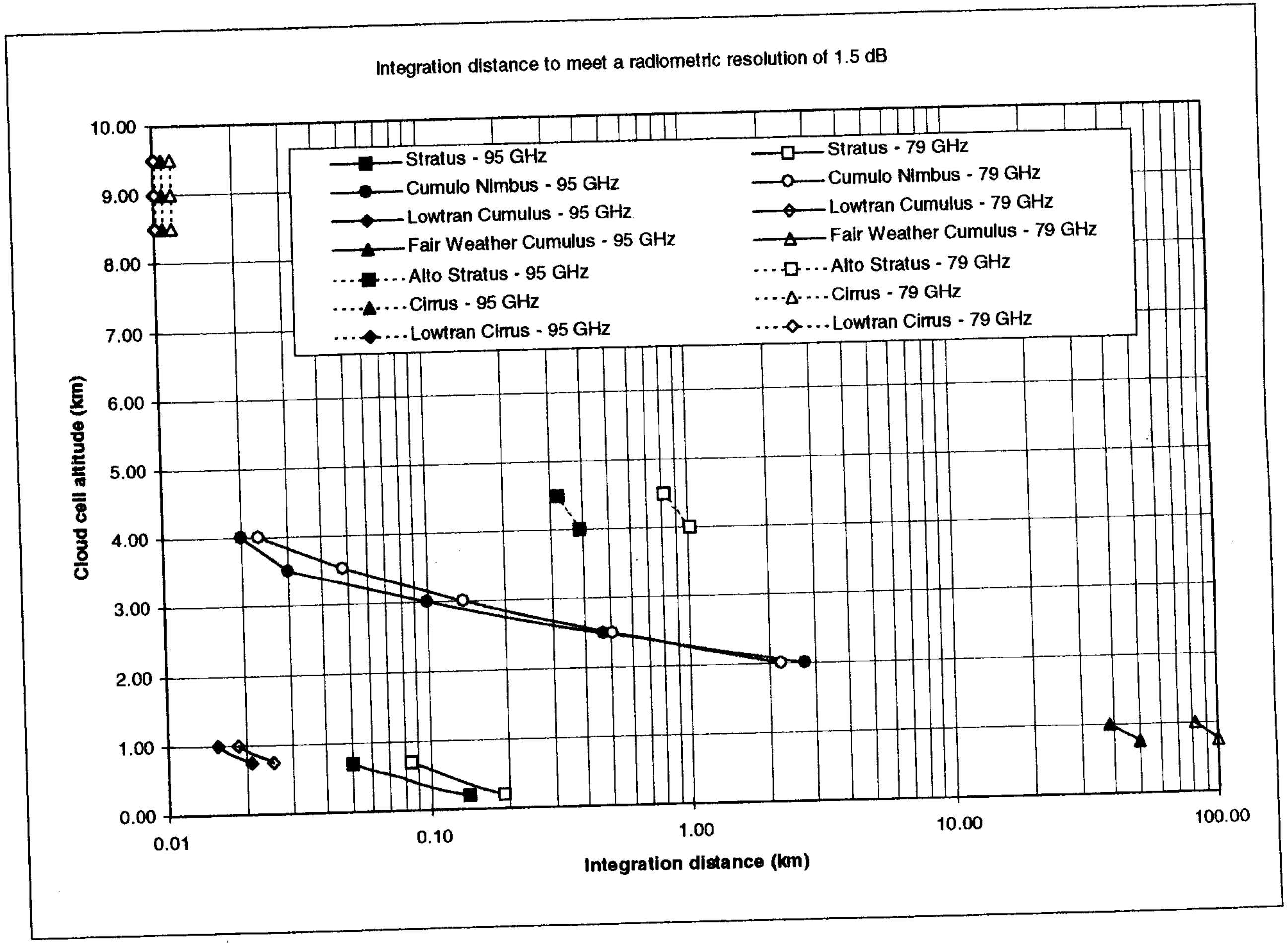


BUDGETS

Unit	Mass (kg)	Power consumption (W)	
		95 GHz	79 GHz
DE s/s	**2 × 7**	**17**	**17**
RF s/s	**2 × 3**	**16**	**16**
Front end s/s with cooling system	**2**	**4**	**4**
HPA s/s	**4 × 12.5**	**159**	**178**
Antenna s/s	**20**	**-**	**-**
Reflector	16	-	-
Mechanisms	4	-	-
Beam Waveguide distribution	**20**	**-**	**-**
3 subreflectors	2	-	-
3 rotating mechanisms	6	-	-
stable baseplate	12	-	-
Data storage	**2 × 3.5**	**15**	**15**
Total with 20 % margin	**140 kg**	**250 W**	**280 W**

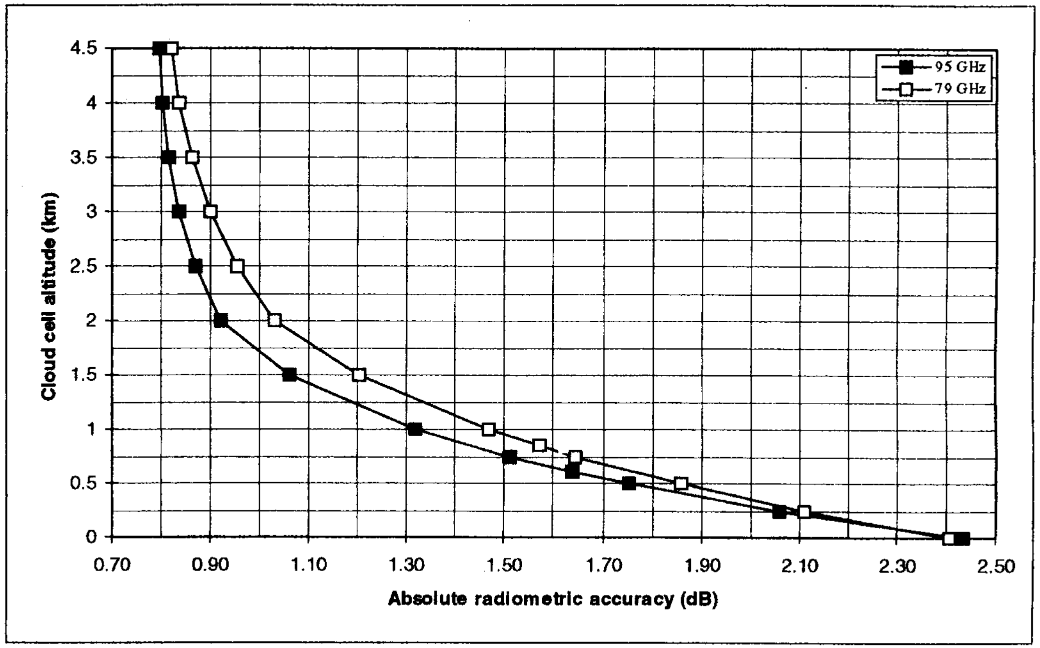
MACSIM performances on specific cloud

Cloud type	Reflectivity (dBZ)	95 GHz Attenuation (dB/km)	79 GHz Attenuation (dB/km)
Stratus	- 20.94	2.09	1.74
Fair Weather Cumulus	- 35.80	0.17	0.14
Lowtran Cumulus	- 12.08	3.91	3.25
Cumulo Nimbus	- 18.69	3.94	3.28
Alto Stratus	- 28.69	0.49	0.41
Cirrus	- 5.08	0.00	0.00
Lowtran Cirrus	1.95	0.01	0.01



MACSIM performances on cloud model

Carrier frequency	95 GHz	79 GHz
Satellite altitude	500 to 600 km	500 to 600 km
Nadir angle	0°	0°
Vertical resolution	500 m	500 m
Antenna beamwidth	0.085 deg	0.102 deg
Antenna gain	66.6 dB	65.1 dB
System temperature	290 K	290 K
NF at the LNA input	2.5 dB	2.3 dB
HPA peak power	1.7 kW	1.9 kW
Reflectivity factor	-30 dBZ min.	-30 dBZ min.
Cloud losses	0.81 dB/km	0.68 dB/km
$\lvert K\rvert^2$	0.6856	0.6856



Satellite altitude : 500 km

An altitude of 600 km degrades sensitivity by 1.6 dB
~ loss of 500 m in minimum detectable altitude

ANTENNA SUBSYSTEM

	f = 79 GHz	f = 95 GHz
Reflector aperture (mm)	2500	
Reflector focal length (mm)	2000	
Reflector clearance (mm)	50	
Reflector offset angle (deg)	33.2	
Reflector half-subtended angle (deg)	31.8	
Horn aperture (mm)	9.0	7.5
Horn phasing section length (mm)	26.7	22.2
Horn flare section length (mm)	6.2	5.2
Horn flare section angle (deg)	20.2	20.2
Horn input section diameter (mm)	2.2	1.8
Horn input section length (mm)	7.1	5.9
Horn length (mm)	40.0	33.3

Main dimensions of the single offset reflector antenna

	f = 79 GHz	f = 95 GHz
Reflector illumination level (dB)	-10	-10
Aperture efficiency (dB)	-0.54	-0.54
Spillover (dB)	-0.51	-0.51
Directivity (dB)	65.26	66.86
Thermal distortions losses (dB)	0.09	0.13
Implementation losses (dB)	0.10	0.12
Gain (dBi)	65.1	66.6
3 dB Beamwidth (deg)	0.102	0.085
SLL ($\theta > 10$ deg) (dB)	-80	-80
Max. crosspolarisation level (dB)	26.7	26.7
Antenna return losses (dB)	33.0	33.0

Electrical performances of the single offset reflector antenna

➡ Single offset configuration :

- simple design and accommodation

- very good gain and SLL

III. TECHNOLOGY AND SUPPORT
B. LIDAR CONCEPTS AND TECHNOLOGIES

INTRODUCTION

A. CULOMA, ESA, EOPP

The ATLID Backscatter Lidar

Technology and Support studies

1 September 1998 Seminar on Radiation Studies

Instrument Technology Pre-development

- Harmonized programme between EOPP, TRP and GSTP
- Aim1: Define an optimized Instrument concept
- Aim2: Identify at an early stage the critical units
- Aim 3: Raise the instrument technology maturity by breadboarding the identified critical units

Instrument technology Pre-development

Breadboarded unit	Objective
Laser Head	Efficiency, high power, thermal control, lifetime
Q-switch and its Electronics	Laser damage/ EMC
Laser Power Supply	Efficiency, EMC
Laser Head Thermal Control	Large heat load, high temperature stability
Telescope	Large diameter, low mass, low inertia
Scan Mechanism	Torque compensation, pointing accuracy, lifetime
Spectral filter & coatings	Narrow-stable bandpass, transmission/ laser damage
Detection chain	Very low noise operation, EMC

Instrument Technology Pre-Development

Breadboard	Industrial Team
Laser Head	Alenia-Difesa, *Quantel, Thomson-CSF, Enosa, Norskk E.O*
Q-Switch and its Electronics	MMS-F, *Thomson-CSF, MMS-F*
Laser Power Supply	Dornier
Laser Head Thermal Control	MMS-UK, *Bradford-Eng., NLR, TAIS Ltd*
Telescope	Carl Zeiss Jena, *DASA-RT, Jenoptik*
Scan Mechanism	ORS, *Oerlikon-Contraves, Laben, VTT*
Spectral Filter & Coatings	DASA-RT, *TecOptics, Carl Zeiss Jena, Jenoptic*
Detection Chain	MMS-F, *EG&G, TPD-TNO*

Support Studies

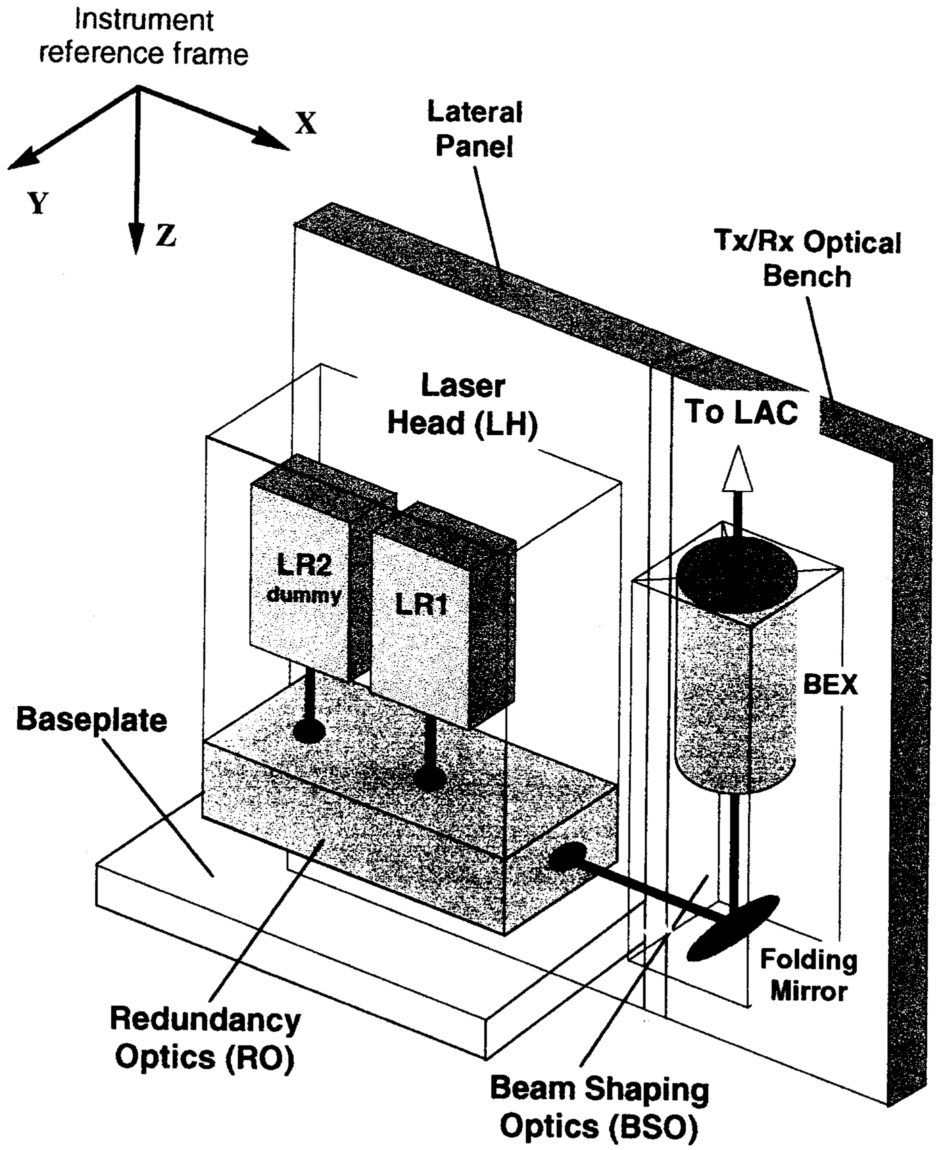
- Assessment of Multiple Scattering Effects on Backscatter Lidar Signal Processing (University of Geneva),
- Lidar Detection Algorithms at Low SNR (University of Geneva, TNO-FEL)

III. TECHNOLOGY AND SUPPORT
B. LIDAR CONCEPTS AND TECHNOLOGIES

LASER HEAD CRITICAL TECHNOLOGY

A. COSENTINO, ALENIA

ATLID Transmitter System schematic



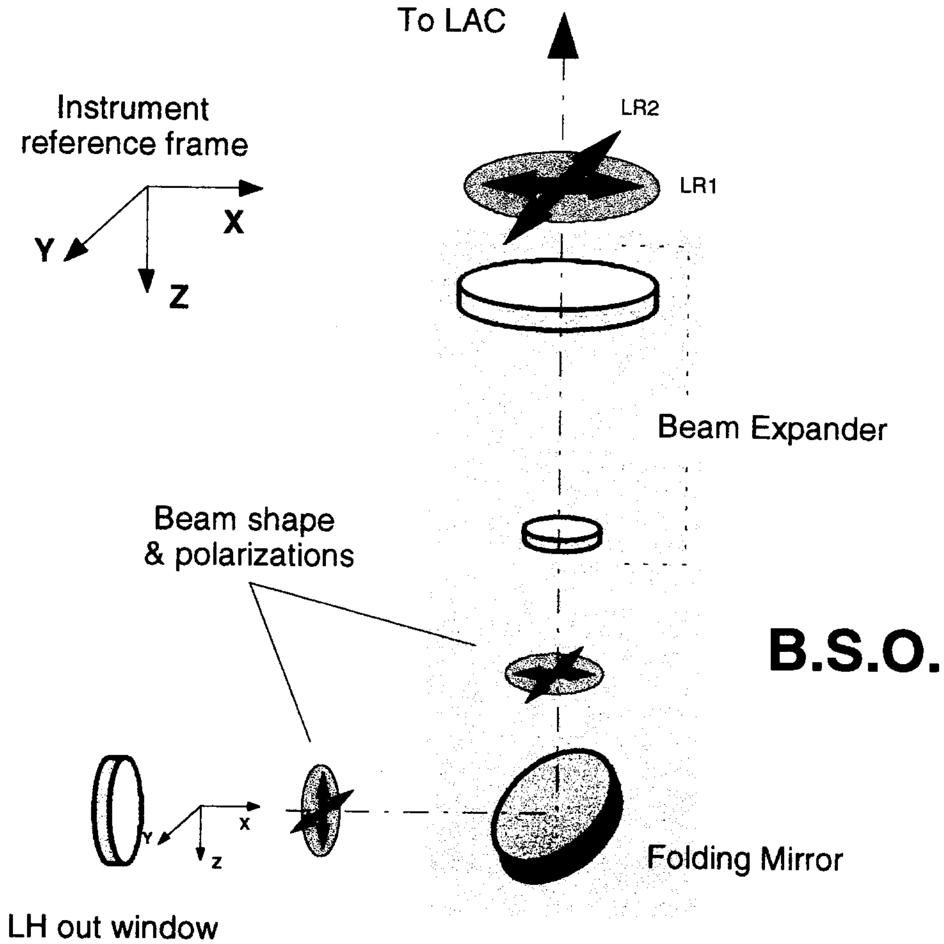
- **The LH is positioned on the lateral panel of ATLID; the laser beam exiting the output window of the LH is sent toward the BSO. The redundancy optics is provided to combine the two lasers (master/back-up) on a single optical channel by means of a polarization cube and to give a far-field circular beam starting from the asymmetric beam produced by the slab laser (LH).**

- **The master Laser Resonator contained inside the optical sub-unit of the LH is a laser diode pumped Nd:YAG laser capable to emit Q-Switched pulses.**

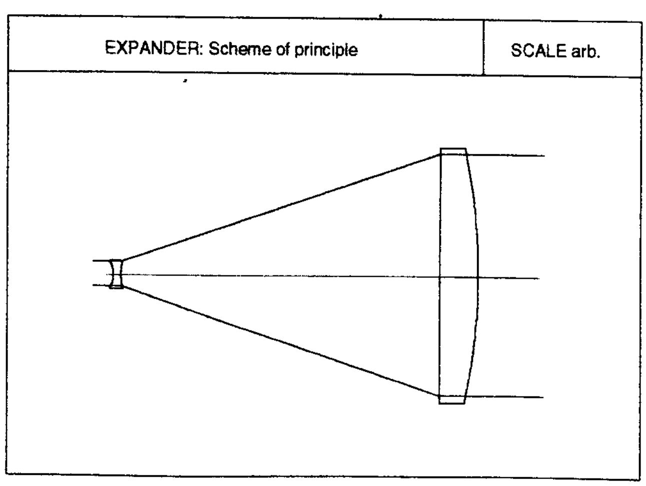
- **The active material is a Nd:YAG slab shaped and transversally optically pumped by two series of four Laser Diode (LD) stacks (TBC).**

Laser Head: Performance Summary table

Pulse energy	≥ 97 mJ
Pulse energy stability	≤ 5% short term (15 s)
	≤ TBD long term (3 years)
Pulse energy knowledge	1 mJ accuracy
Peak wavelength	1063.65 nm (TBC)
Peak wavelength stability	+/- 0.01 nm long term (TBC)
Laser FWHM Linewidth	≤ 0.1±0.01 nm
Pulse Repetition Frequency	100 +/- 1Hz
PRF adjustment range	90 - 110 Hz
Polarization	
Type	Linear
Purity	50:1 extinction ratio
Orientation	Along Y axis
Mode structure (Transversal)	Near TEM_{00}
Mode structure (Longitudinal)	Multimode
Beam dimensions	≤ 6.3 x 4.3 mm (Y dir. x X dir.)
Beam divergence	≤ 1.2 mrad
Beam decenter stability	≤ ± 0.5 mm long term
Beam angular stability	≤ ± 50 µrad short term
	≤ ± 100 µrad long term
Total mass	≈ 20 Kg
Total volume	≈ 300x130x425 mm^3
Environmental conditions	see ATLID specs



Preliminary optical layout of the BSO. The elliptical shadow is common to the two LRs beams but the polarization directions are crossed.

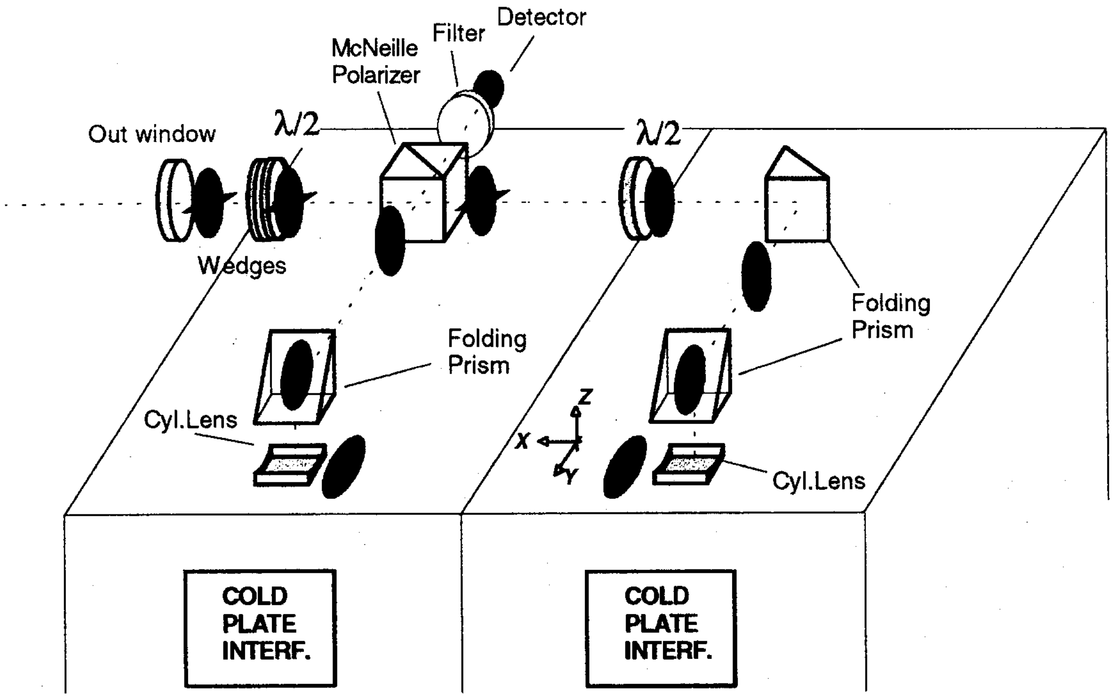


Schematic of the optical layout for the BSO expander

BSO: Performance Summary table

Operating wavelength	1064 nm
Spectral bandwidth	≥ 10 nm
Magnification factor	7x (TBC)
Input clear aperture	≥ 10 mm
Output clear aperture	70 mm
Input far-field divergence	1200 µrad (TBC)
Input beam dimensions ($1/e^2$)	6.6 x 4.4 mm (TBC)
Input beam axis incidence	± 200 µrad
Input beam decenter	± 0.5 mm
Output far-field divergence	= input divergence/ magnification
Output beam dimensions	= input dimensions x magnification
Maximum wavefront distorsion	≤ λ/10 RMS (@ λ=1064nm)
Total transmission	≥ 97% (@ λ=1064nm)
Maximum Power Density (with PRF=100Hz, τ=20ns)	≤ 50 MW/cm^2 (on folding mirror)
Total mass (mech. housing included)	6 Kg (TBC)
Total volume (mech. housing included)	104(diam.) x 186(len.) mm (TBC)
Mounting	quasi isostatic
Thermal ranges	-20°C < $T_{operational}$ < 40°C (TBC)

Redundancy Optics

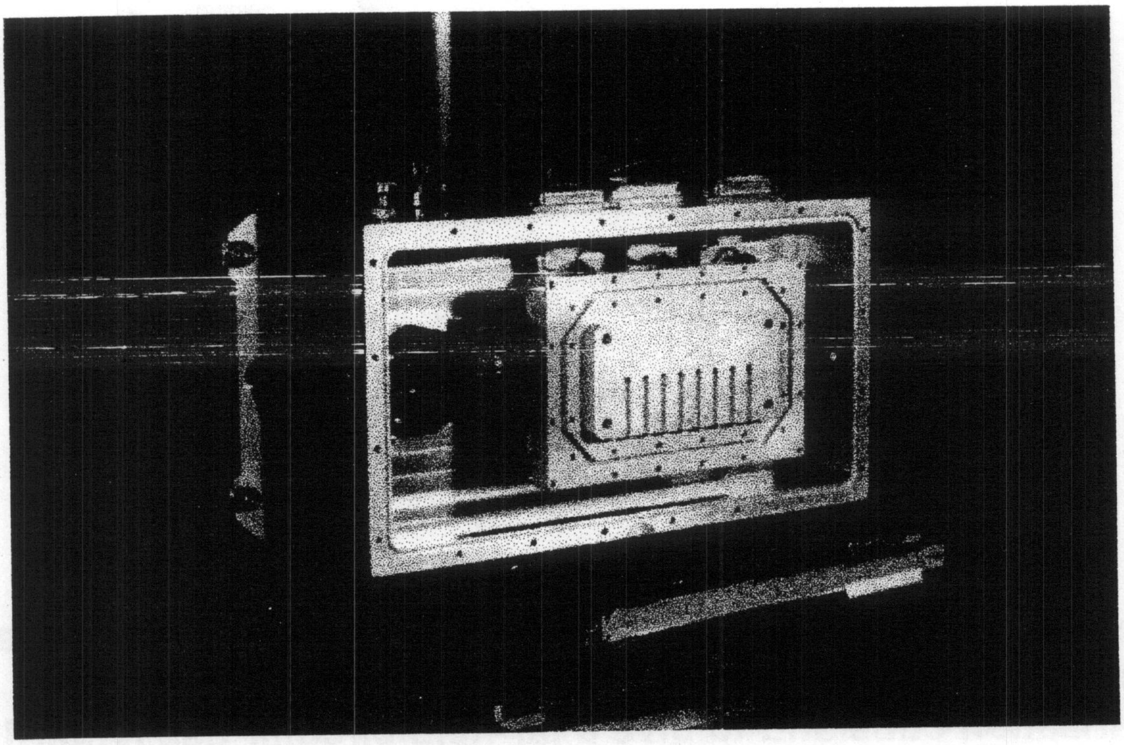


Schematic of the Redundancy Optic architecture (TBC)

The redundancy optics is provided to combine the two lasers (master/back-up) on a single optical channel by means of a polarization cube and to give a far-field circular beam starting from the asymmetric beam produced by the slab laser (LH).

Inside the Redundancy Optics it is also contained the energy monitor that measures the energy emitted by the operating laser over the TX lifetime.

DPL-10



ESTEC CONTRACT N. 8989/90/NL/MD

STUDY LOGIC

Main purposes of the study

- verify the laser diode pumping feasibility for high power spaceborne lasers
- verify the applicability of a conductive cooling concept
- develop a laser structure capable to withstand the requested environmental conditions
- demonstrate potential lifetime and reliability increase with respect to the flashlamp pumped lasers

Development activities

- laser opto/thermal/mechanical/electrical configuration selection
- laser housing design/manufacturing/test
- mechanical supports design/manufacturing/test

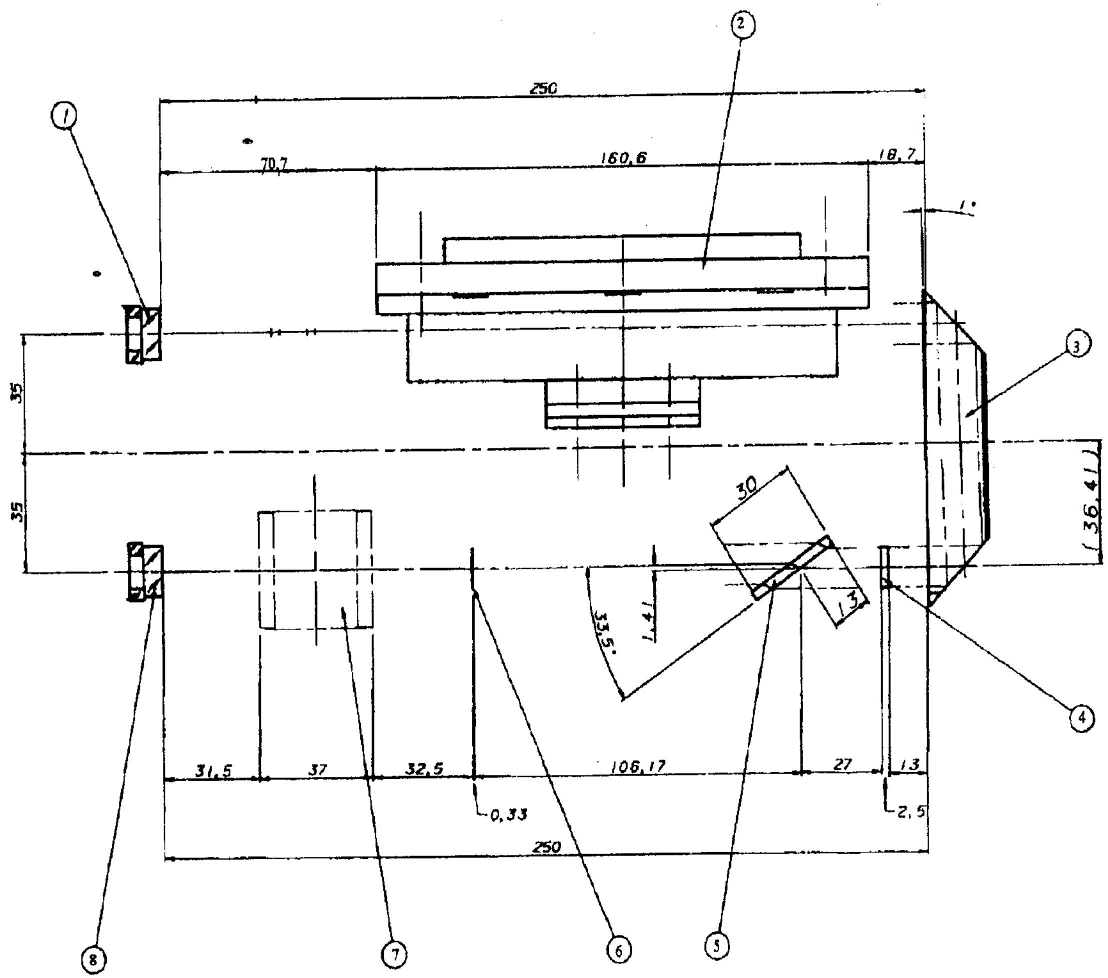
Under this contract no development activity has been forseen for

⇒laser electronic unit (LDPS, Q-SPS, etc.)

⇒electro/optical components (with the exception of laser diodes for which a partial "customization" from the supplier was needed)

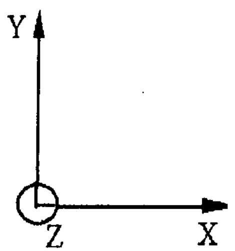
LASER OPTICAL LAY-OUT

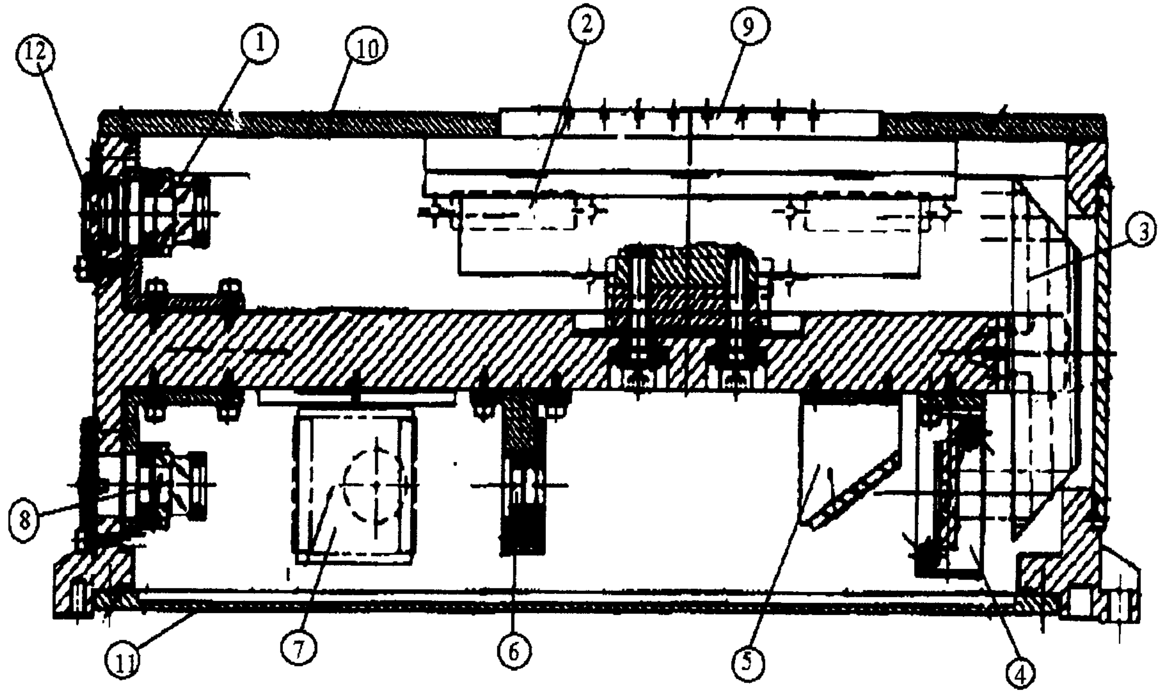
1 Output Mirror
2 Pumpt Cavity
3Folding Prism
4 Compensating Lens
5 Polarizer
6 Quarter Waveplate
7 Q-Switch
8 Back Mirror



OPTO/MECHANICAL COMPONENTS LOCATION

1 Output Mirror
2 Pump Cavity
3 Folding Prism
4 Cylindrical Lens
5 Polarizer
6 Quarter Waveplate
7 Q-Switch
8 Back Mirror
9 Cold Plate Fixing
10 Lexan Cover
11 Aluminum Cover
12 Output Window





D P L - 10
DIODE PUMPED LASER

GENERAL ARCHITECTURE AND INTERFACE DEFINITION

MECHANICAL

- RIGID HOUSING STRUCTURE AND TWO OPTICAL BRANCHES FOR LASER CAVITY WITH FOLDING PRISM
- TOTAL CAVITY LENGTH 580 MM WITH TOLERANCE OF +/- 5 MM
- INTERFACE SEPARATION BETWEEN THE MECHANICAL REFERENCE AND THE THERMAL REFERENCE
- MECHANICAL REFERENCE WITH THREE FIXING POINTS FOR ISOSTATIC MOUNTING

D P L - 10
DIODE PUMPED LASER

GENERAL ARCHITECTURE AND INTERFACE DEFINITION

- RESONATOR HOUSING SEALING WITH O-RING GASKETS LOCATED IN THE COVERS GROOVE
- V-SHAPE SLOT ON THE RESONATOR BASEPLATE FOR PUMP CAVITY MOUNTING TO MINIMIZE RELATIVE DEFORMATIONS
- RESONATOR HOUSING SURFACE TREATMENT WITH CHROMIUM CONVERSION COATING

D P L - 10
DIODE PUMPED LASER

GENERAL ARCHITECTURE AND INTERFACE DEFINITION

THERMAL

- EXTERNAL LIQUID COOLANT COLDPLATE MOUNTED ON THE THERMAL REFERENCE INTERFACE
- THERMAL LOADS (150 WATTS) FROM PUMP CAVITY TRANSFERRED TO THE THERMAL INTERFACE BY CONDUCTION
- LASER DIODES ON COPPER HEAT SINKS WITH ELECTRICAL INSULATING BeO HEAT SPREADERS
- ACTIVE LASER MEDIUM Nd:YAG CLAMPED ON PUMP CAVITY SURFACE FOR DIRECT CONDUCTIVE COOLING

D P L - 10
DIODE PUMPED LASER

GENERAL ARCHITECTURE AND INTERFACE DEFINITION

ELECTRICAL

- LASER DIODES CONNECTED AS A PARALLEL OF TWO SERIES (4 DIODES EACH SERIES)
- LASER DIODES ELECTRICAL POWERING FOR THE PARALLEL-SERIE CONNECTION WITH CURRENT 2 X 75 AMPS AND VOLTAGE 2 X 55 VOLTS
- HIGH VOLTAGE CONDUCTORS PAIR FOR THE Q-SWITCH IN COPPER WITH MAXIMUM RATE CURRENT 30 AMPS AND VOLTAGE 5000 VOLTS
- ELECTRICAL CONNECTORS: TYPE D-25P HERMETIC FOR LASER DIODE POWERING AND HIGH VOLTAGE FEEDTHROUGH FOR THE Q-SWITCH

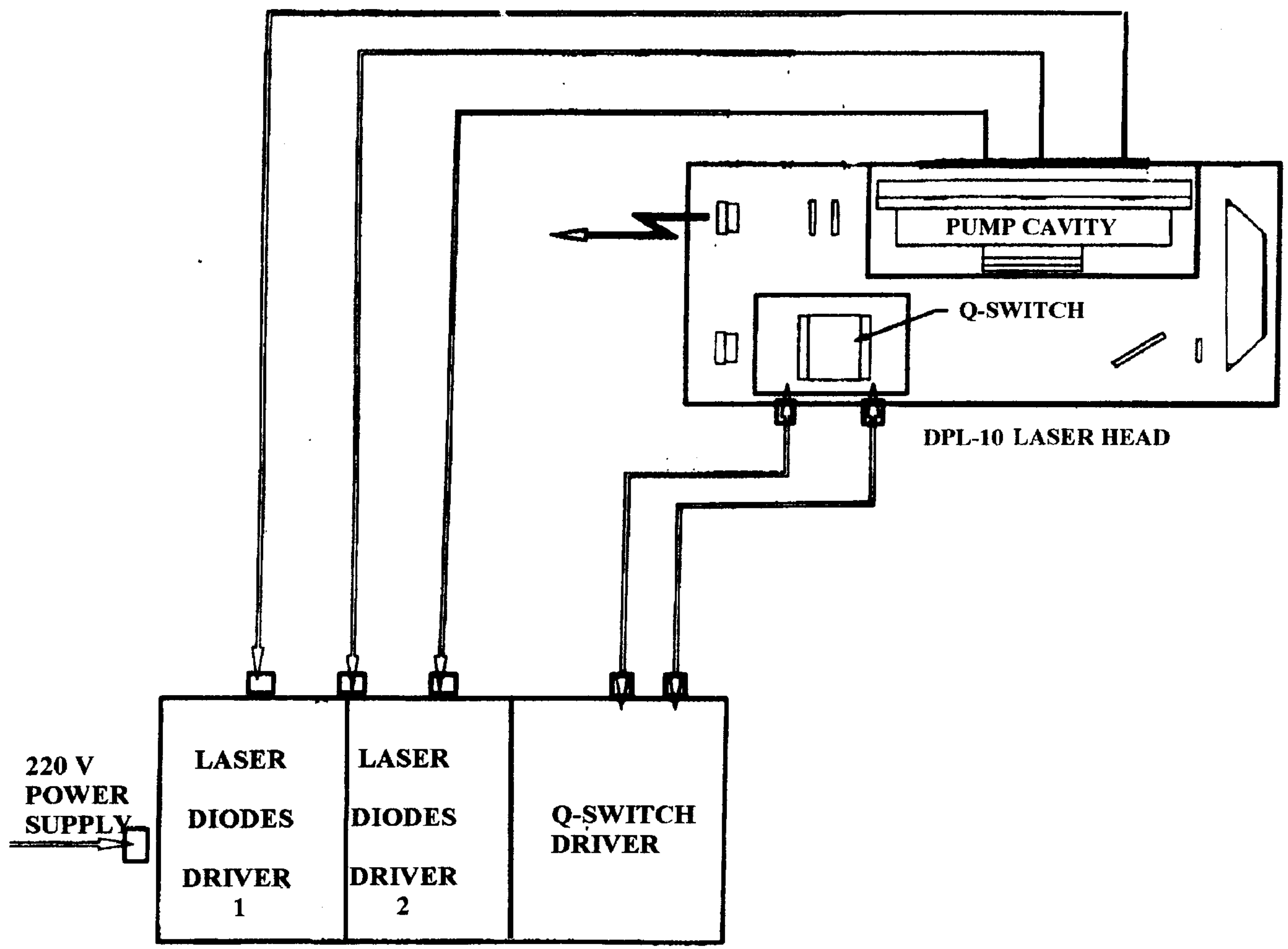
D P L - 10
DIODE PUMPED LASER

GENERAL ARCHITECTURE AND INTERFACE DEFINITION

OPTICAL

- UNSTABLE RESONATOR WORKING IN THE POSITIVE BRANCH
- SUPERGAUSSIAN OUTPUT MIRROR (n = 3)
- SLAB ACTIVE MEDIUM. ZIG-ZAG PATH OF1.064 μm RADIATION (11 BOUNCES)
- DIRECT COUPLING BETWEEN SLAB AND LASER DIODES (0.5 mm DISTANCE)

LASER ELECTRICAL LAY-OUT



ACCEPTANCE TEST RESULTS

Laser operating conditions:

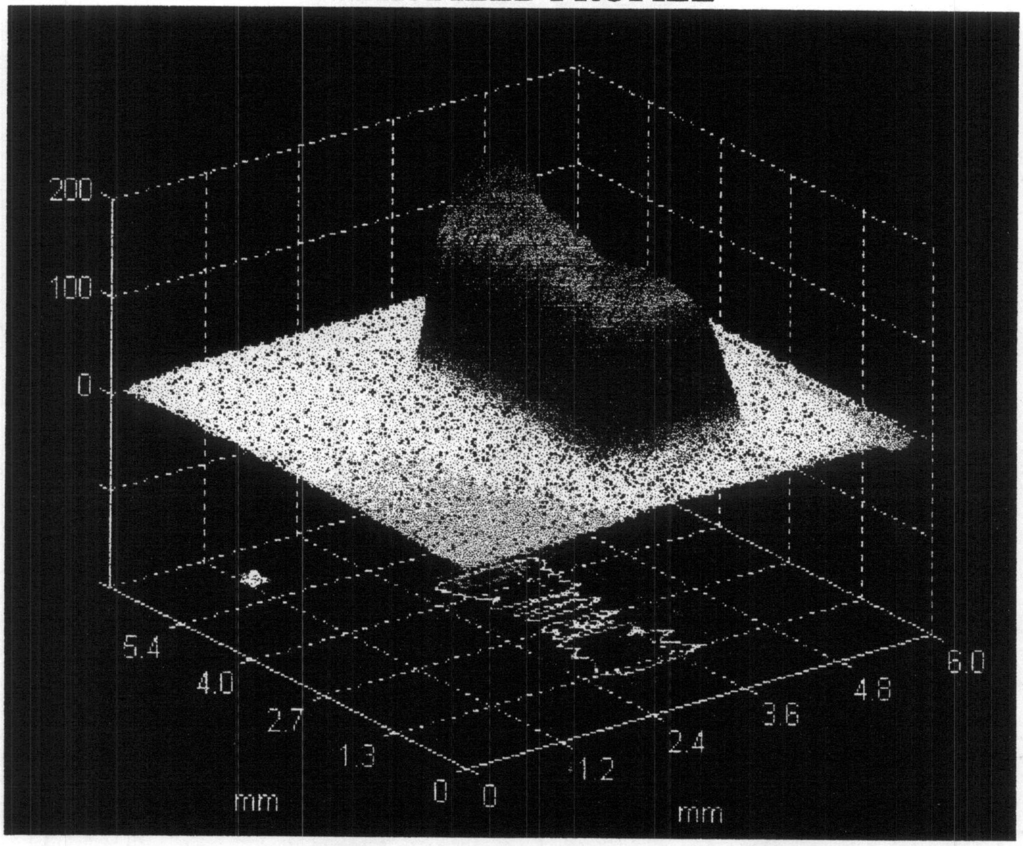
I_{OP} = 72 A, PRF = 100 Hz, HV Q-Switch = 3000 V,

LD Heatsink Temp. = 22 °C

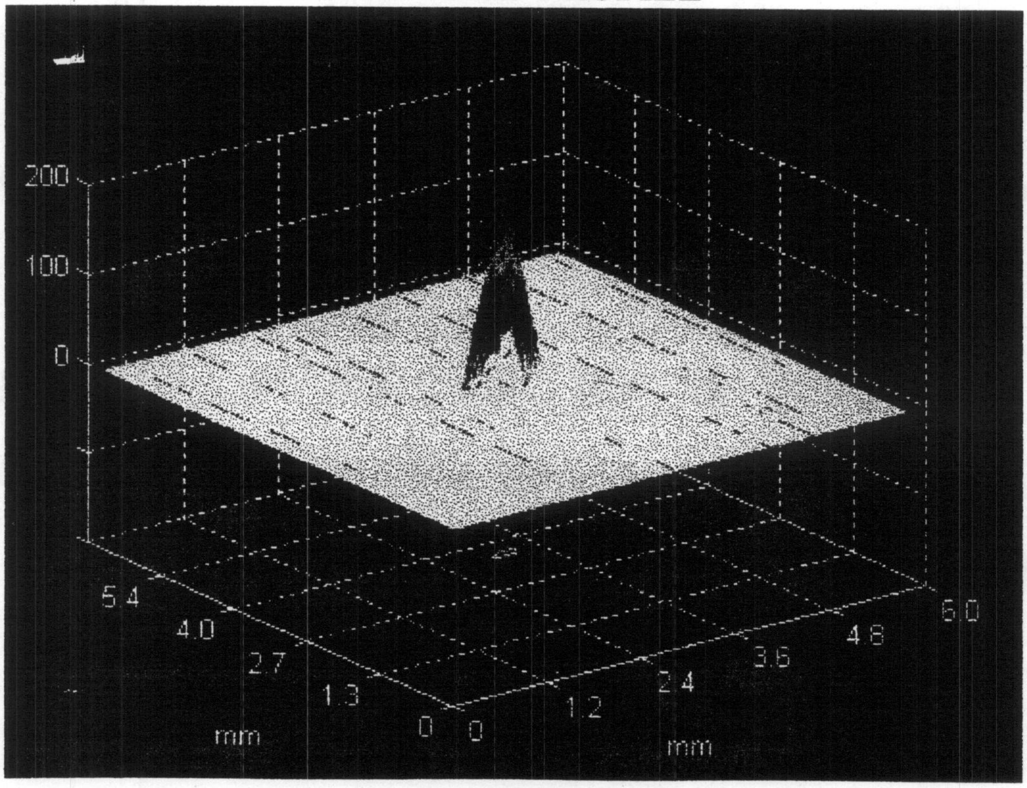
Obtained Results:

QUANTITY	DPL-10 REQUIREMENT	MEASURED VALUE
Emission wavelength	1.064 μm	10642.9 ± 0.1 Å (T_{amb} = 27 °C/P_{amb} = 970 mbar)
Output mean power	≥ 10 W	10 W
Pulse Repetition Rate	100 ±1 Hz	100 Hz
Pulse Duration	20 ns	≈ 18 ns
Pulse to Pulse Energy Stability	± 5 %	± 2 %
Type of Output	Near TEM_{00}	M^2 (Hor.) ≅ 1.5; M^2 (Ver.) ≅ 1
Polarization	Linear	Ext. Ratio ≅ 0.01
Beam Angular Stab.	≤ 100 μrad	≤ 50 μrad (half angle)
Beam Linewidth	1 ± 0.1 Å	0.59 ± 0.04 Å
Overall Efficiency (el./opt.)	≥ 5%	≈ 6.5 %

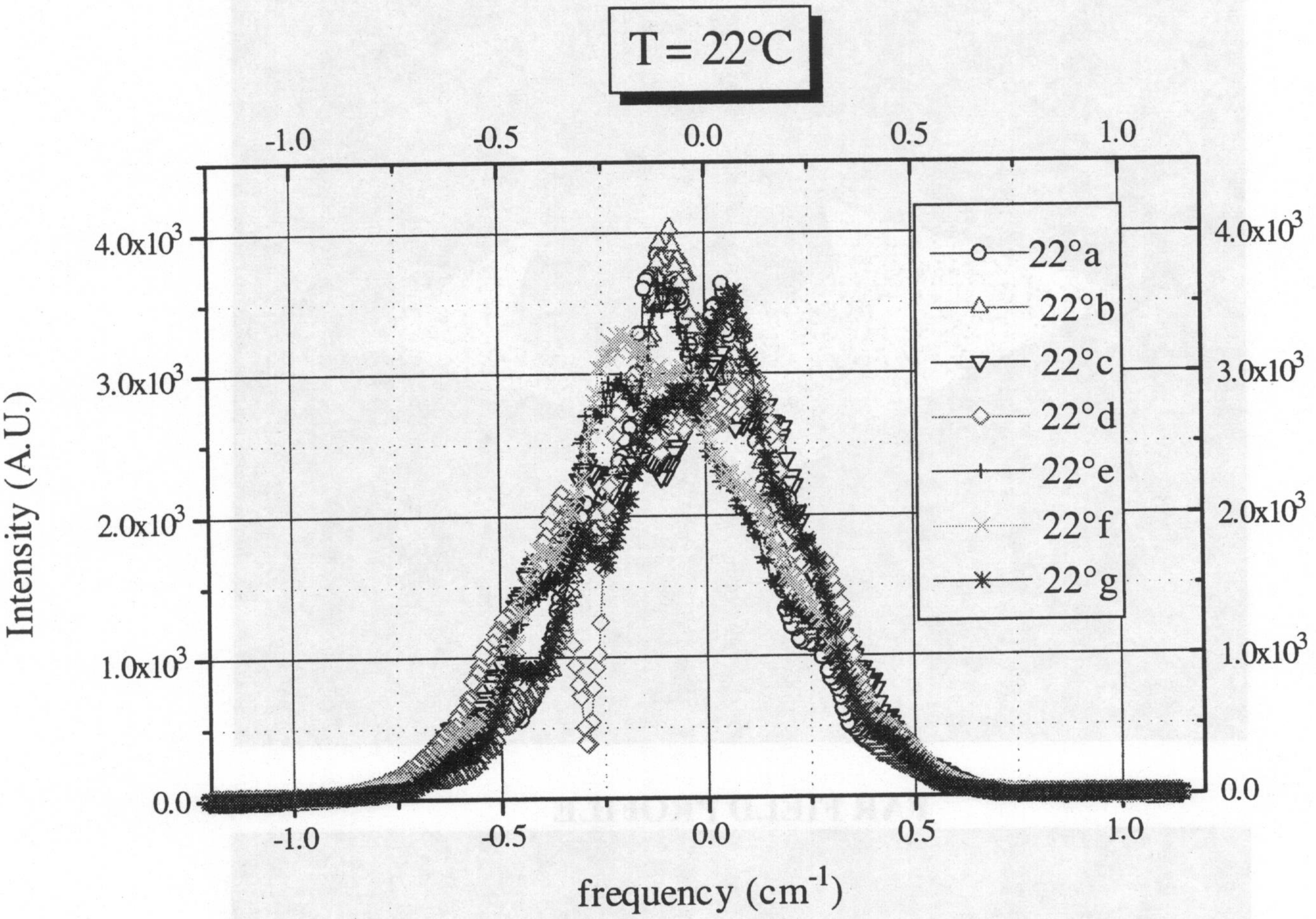
NEAR FIELD PROFILE



FAR FIELD PROFILE



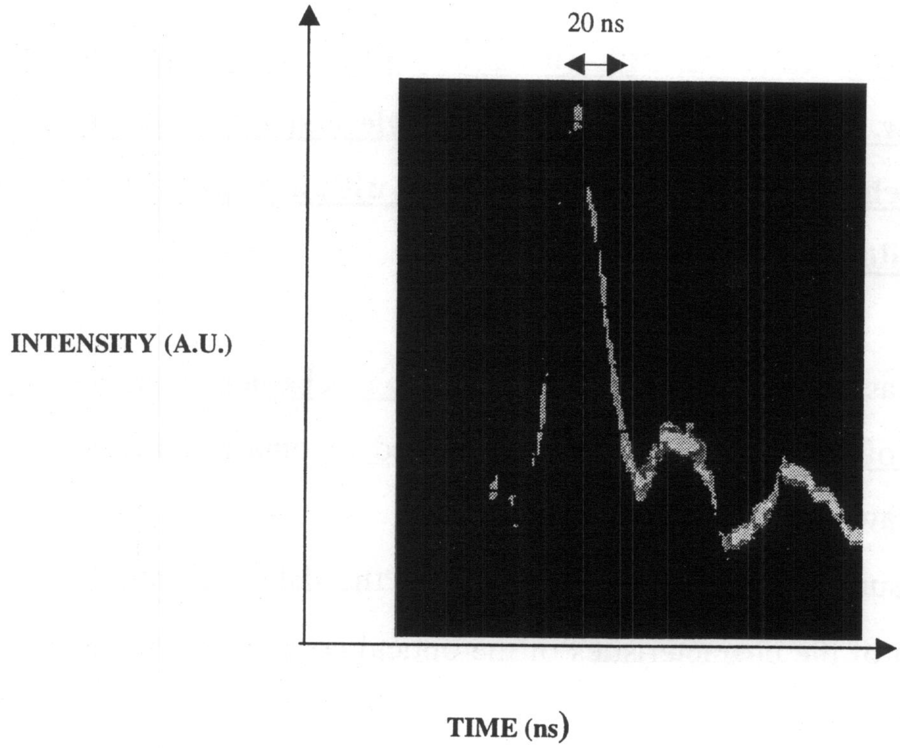
LASER LINEWIDTH



1 cm^{-1} corresponds to 1 Angstrom and 1 Angstrom corresponds to about 26.5 GHz (at 1 μm wavelength).

From our results we can infer that the laser emission wavelength as well as its linewidth are **not influenced by temperature changes** ***of the laser environment.***

PULSE SHAPE



ENERGY STABILITY

The measured value is:

± 2% on a time period of 1 minute

BEAM POINTING STABILITY

The measured values are:

± 30 μrad in the vertical plane

± 50 μrad in the horizontal plane (zig-zag plane)

CONCLUSIONS AND RECOMMENDATIONS

The obtained results show that the DPL-10 laser is fully compliant from the functional point of view. This demonstrates that a single resonator, 10 W mean power, 100 Hz, Q-Switched laser diode pumped laser, with a good beam spatial quality ($M^2 < 2$), is feasible.

⇒ The **slab** utilization has shown the advantage of an easy mechanical fixing concept and a reduced level of distortions. This latter allowed to obtain a better beam spatial quality. The drawbacks of this choice were:

- high degree of surfaces quality (high criticality in the slab machining).
- accurate design of the characteristics of the optical coatings to be deposited on slab surfaces.
- the zig-zag path inside the slab makes the whole laser alignment more difficult.

⇒ The design choice of a **positive branch unstable resonator** allowed to realize a single more compact cavity, also reducing *the risk of components damagements* due to the internal focal points absence.

The only internal component that suffered damagements during the optimization phase, was the Q-Switch. The study and the characterizations performed demonstrated that this problem arises from the laser functionment in a non perfect confocal configuration, strictly related to the resonator geometrical parameters and the pumping characteristics. It should be anyway desirable to increase the Q-Switch damagement threshold to 1 GW/cm^2.

CONCLUSIONS AND RECOMMENDATIONS

⇒ It has been also demonstrated that **the fully compliance with the environmental conditions is possible**. The laser withstand the thermal and the sinusoidal vibration cycles without any damagement. *Only the random vibrations along a critical axis created a slab damagement*, but essentially due to an ungluing of this component.

This problem does not seem to require a new design of the slab mechanical mounting, but simply a modification of the shape and area of the active material glued zone. Particularly, a modification of the upper plate could allow an increase of the glueing area and the introduction of the glueing on both the slab sides, already realized during the tests, could be kept. Also a redesign of the lateral flexure, aimed to increase the mounting stiffness, should be desirable. On the contrary,the reinforcing of the end springs must be avoided because it could be cause of the slab deformation, absolutely unacceptable from the optical point of view.

⇒ Always **during the random vibrations**, it was noticed a scraping of the slab with the PC surface that can cause a coating damagement detrimental for the optical efficiency of the whole laser.

Even in this case a modification of the interface slab/PC aimed to decrease the contact friction should solve this problem. For this purpose a PC machining with lower tolerance for roughness and flatness should be implemented.

CONCLUSIONS AND RECOMMENDATIONS

⇒The **H-shaped laser housing concept** allowed to obtain a compact resonator and during the environmental qualifications showed a good dynamic behaviour.

⇒ The **experimental validation of the design devoted to separate the mechanical interface from the thermal one** was not performed completely because of the non availability of thermally qualified laser diodes.

⇒ The experience matured in the **mirror supports** design put in evidence the extreme criticality of the specifications which require at the same time a highly sensitive system with a good stiffness able to withstand very heavy vibration levels.

⇒ All the **other mechanical mounts** showed a good thermal and dynamic behaviour, even if some of them should be improved in terms of adjustments. In fact the Q-Switch support adjustment sensitivity could be increased and the cylindrical lens support should be provided with a rotation about its working axis.

⇒ The **present laser functional performance** are near to the best one obtainable with this configuration.

An increase of the output power would involve a complete laser redesign even keeping the most part of the actual mechanical and optical concepts.

III. TECHNOLOGY AND SUPPORT
B. LIDAR CONCEPTS AND TECHNOLOGIES

TECHNOLOGIES FOR ATMOSPHERIC LIDAR (ATLID)

C. MORANCAIS, MMS-F

TECHNOLOGIES FOR ATMOSPHERIC LIDAR (ATLID)

D. Morançais **MATRA MARCONI SPACE**

- **Overview on developed technologies**
- **Focal Plane optics**
- **Detection chain**
- **Laser support technologies**

OVERVIEW ON DEVELOPED TECHNOLOGIES

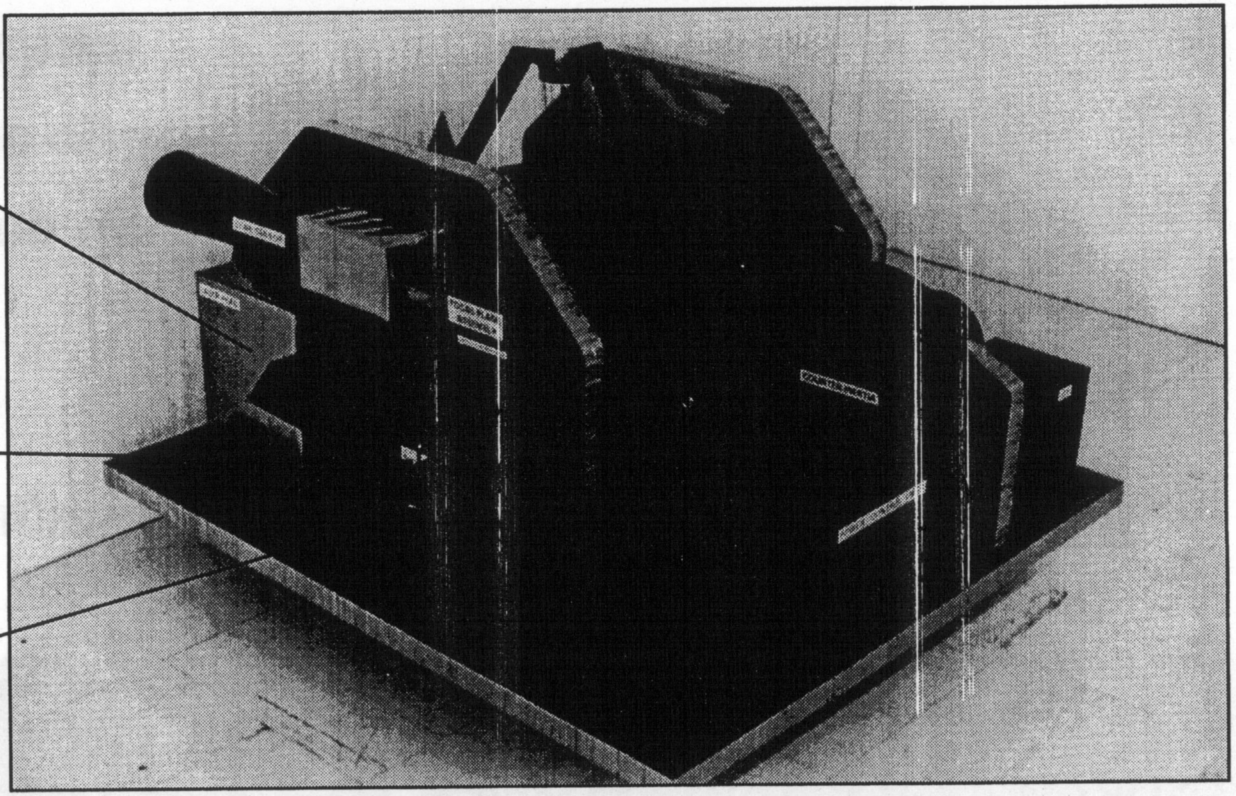
Diode-pumped

Nd-YAG laser

+ support systems

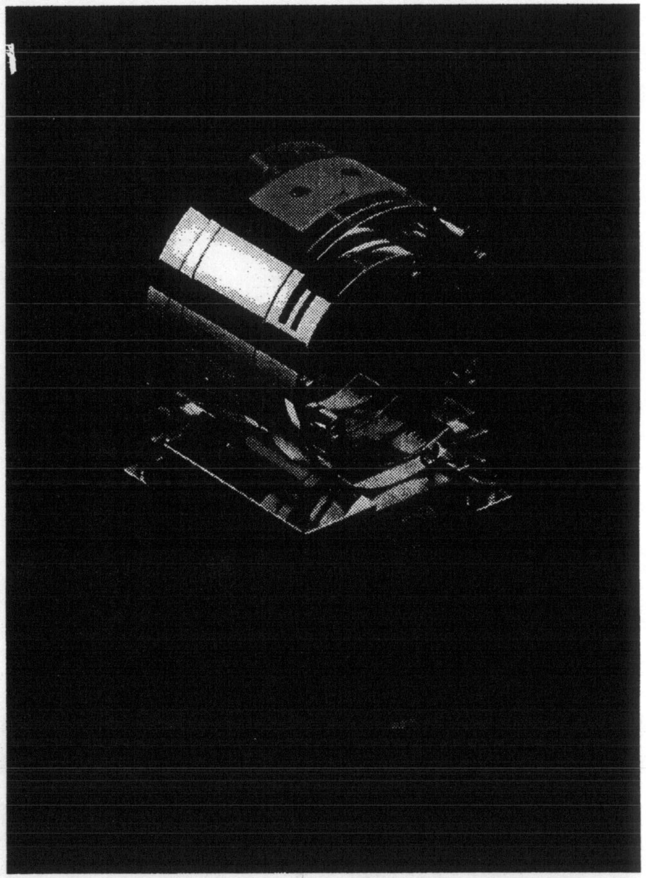
Focal Plane
Optics
(Filter, coatings)

APD
Detection
Chain



FABRY-PEROT FILTER

- Etalon + blocking filter
- 0.2 nm FWHM
- Peak transmission : 0.63
- Tested vs mechanical and thermal environment



QUALIFIED LASER COATINGS

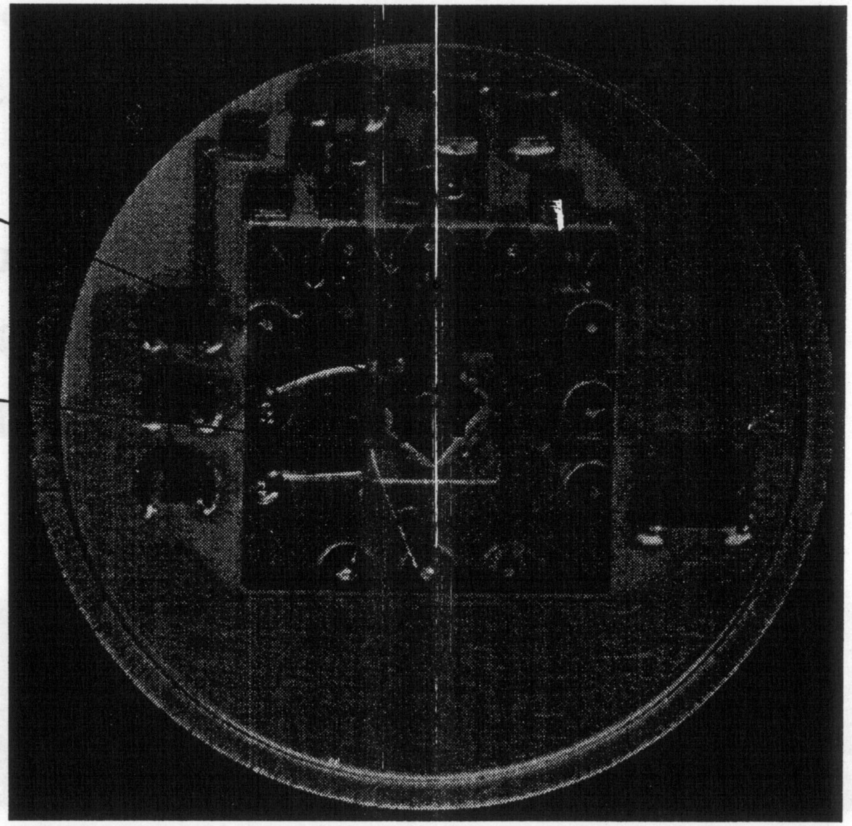
- High energy reflection coatings
  - Reflection > 99.3 %
  - Damage threshold > 15 J/cm2 (requirement < 1 J/cm2)
- AR laser coatings
  - Transmission > 99.7 %
  - Damage threshold > 30 J/cm2
- Low depolarization coatings
- All coatings have been submitted to
  - lifetime tests
  - MIL qualification standards

DETECTION CHAIN (1)

- Front-end
  - Silicon Avalanche Photodiode (APD)
  - APD on Peltier cooler
  - APD / Preampli hybrid
- Two parallel analog chains
  - Radiometric chain ('low bandwidth')
  - Peak detection chain ('threshold detection')
  - 12 bit ADC, 4 MHz
- Performance
  - SNR = 2 for 60 pW signal & 230 pW background
  - (requirement: SNR > 1.2 under same conditions)

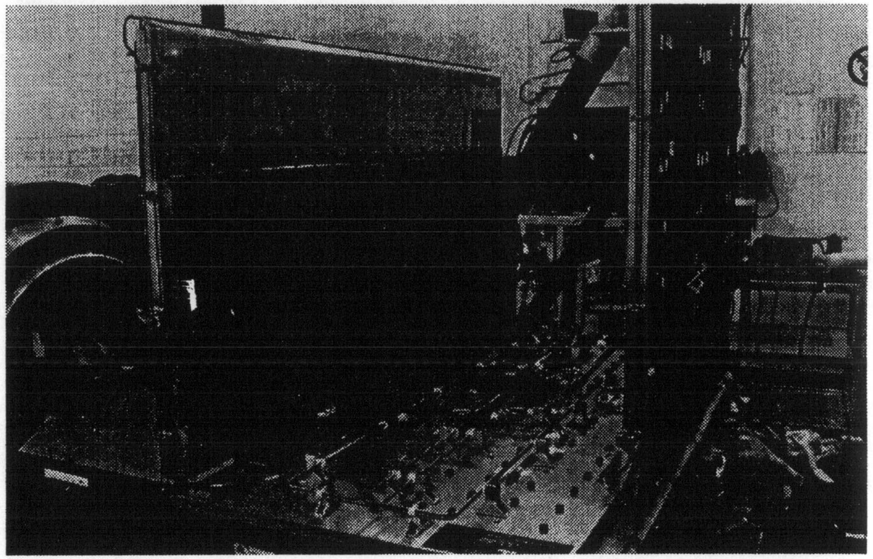
DETECTION CHAIN (2)

APD / Preamplifier Hybrid



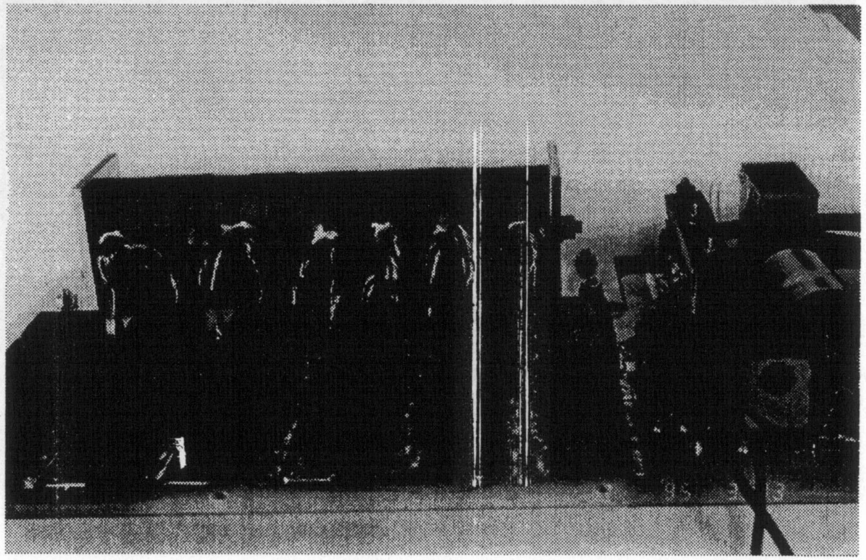
LASER SUPPORT TECHNOLOGIES (1): FLUID LOOP

- Two-phase fluid loop
  - Ammonia fluid
  - Capillary pump
  - Control reservoir
- Performance & tests
  - Laser cold plate cooled at 5° C
  - Regulation to better than ± 1 °C
  - heat capacity above 230 W
  - Passed vibration / TV tests



LASER SUPPORT TECHNOLOGIES (2) : DIODE POWER SUPPLY

- Two-stage architecture
  - DC/DC charger (28 V to 120 V)
  - Pulse Forming Network (PFN)
  - 85 A , 200 µs current pulse
- Performance & tests
  - 74 % efficiency
  - EMC / thermal tests passed



LASER SUPPORT TECHNOLOGIES (3) : POCKELS CELL

- Pockels cell (under development)
  - KD*P crystal with moisture insensitive crystal
  - Power capability > 1 GW/cm2 (requirement 300 MW/cm2)
  - Extinction ratio: 1/4000
  - EM standard (will be submitted to vibrations and thermal tests)
- High voltage driver
  - 4 KV output pulse
  - Switching time: 10 ns (MOSFET switches)
  - Passed EMC tests

III. TECHNOLOGY AND SUPPORT
C. PASSIVE SENSOR CONCEPTS AND TECHNOLOGIES

INTRODUCTION

R. MEYNART, ESA, EOPP

Passive instruments

- Two complementary passive instruments
  - Cloud imager
    - 2 VIS, 1 SWIR and 2 TIR bands
    - 1 km pixel, short swath (100-300 km)
  - Broadband radiometer
    - 1 short-wave, 1 total channel
    - 30 km pixel, short swath

Cloud imager

- Band definition shows similarity with existing instruments

	Cloud imager	AATSR	AVHRR	SEVIRI
VIS1	0.649-0.669	0.649-0.669	0.58-0.68	0.60-0.67
VIS2	0.875-0.875	0.855-0.875	0.725-1.00	0.775-0.845
VNIR	1.58-1.64	1.58-1.64	1.58-1.64	1.57-1.71
TIR1	8.5-8.9	-	-	8.5-8.9
TIR2	10.4-11.3	10.4-11.3	10.3-11.3	10.3-11.3

- Instrument can be made using European heritage in scanners and pushbroom imagers
  - First assumption: AATSR (Granada)
  - Optimisation of AATSR for ERM (RAL, 1996)
  - Pushbroom design by Officine Galileo using
    - Cooled TIR HgCdTe detector arrays (1997)
    - Uncooled TIR bolometer arrays (1998)
- Supporting technology: development of optimised bolometer array (in preparation)

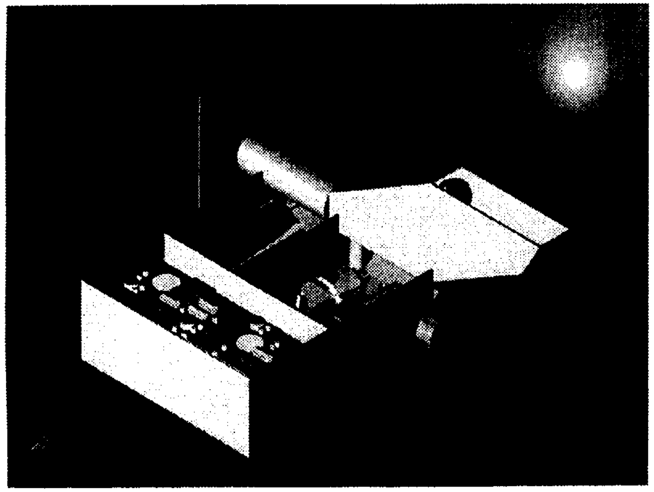
Broadband radiometer

- European heritage: SCARAB, GERB
- US CERES could also be considered
- Initial assumption: SCARAB (Granada)
- Definition of an optimised broadband radiometer by REOSC (1998)

III. TECHNOLOGY AND SUPPORT
C. PASSIVE SENSOR CONCEPTS AND TECHNOLOGIES

A CLOUD IMAGER FOR THE ESA EARTH RADIATION EXPLORER MISSION

D. GIUNTI, D. LABATE, ALENIA



A CLOUD IMAGER FOR THE ESA EARTH RADIATION EXPLORER MISSION

C. Giunti, D. Labate
Alenia Difesa - Un'azienda Finmeccanica - Divisione Sistemi Avionici
Officine Galileo, Via A. Einstein 35, I-50013 Campi Bisenzio (FI), Italy

ESA/ESTEC - Noordwijk(NL) - 1 September 1998

INTRODUCTION

- The present baseline of the Earth Radiation Explorer Mission of the European Space Agency includes two active instruments (cloud radar and backscatter lidar) and two passive instruments (cloud imager and broadband radiometer).

- The cloud imager would allow improvement of the scientific performance of this mission by providing complementary data, as scene and cloud type identification, to those provided by the others instruments.

- Considering the constraints resulting from these instruments, the accommodation of this imager seems to be critical unless a dedicated system is fit up in the platform.

- The goal of this study was to investigate an instrument concept as flexible in accommodation, compact and low-power as possible and suitable to meet the specific mission requirements.

INSTRUMENT MAIN SPECIFICATIONS (STUDY PHASE)

Orbit Specification
Sun-synchronous Mean altitude : 500 Km Descending nodal crossing time : 14:00
Geometrical Parameters
Swath : ≈ 300 km Spatial Sampling Interval (SSI) : 600 m Coverage by pushbroom technique
Spectral Wavebands
Band 1: 0.649 - 0.669 μm - VIS Band 2: 0.855 - 0.875 μm - NIR

Band 3:	1.580 - 1.640 μm	- SWIR
Band 4:	8.500 - 8.900 μm	- TIR 1
Band 5:	10.400 - 11.30 μm	- TIR 2

The geometrical parameters values are the result of a trade-off during which the implications of different values ranges have been examined and discussed with ESA.

In fact, with the selected spatial sampling interval (SSI) is possible to

cover the swath on ground with focal plane arrays of 500 pixels.
This avoids heavy focal planes customization, as for example, the butting of several arrays.

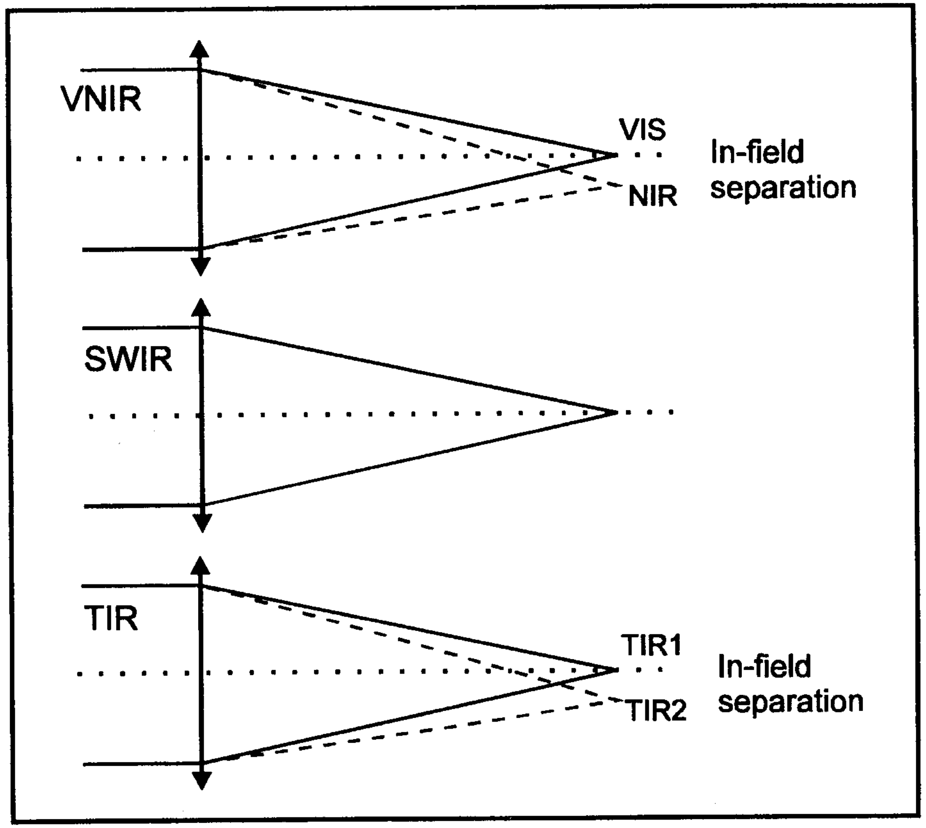
Two study phases have been developed

Detection of thermal IR bands based on:

- Cooled quantum detectors at 65 - 70 K
- Uncooled microbolometer detector at room temperature.

OPTICAL CONCEPT

Considering the opto-mechanical aspects a solution with three different objectives and in-field separation on focal plane for VNIR and TIR bands has been considered as the best compromise between design and development complexity and possibility to obtain an instrument of reduced size.


VNIR
VIS
NIR
In-field separation
SWIR
TIR
TIR1
TIR2
In-field separation

DETECTORS

Focal planes	
VNIR focal plane	- Bilinear Si CCD or two lines of an area array - 512 pixels for row - Pixel size 13 μm
SWIR focal plane	- InGaAs linear array - 300 (512) pixels - Pixel size 30 μm
TIR focal plane	- HgCdTe bilinear array - 512 pixel for row - Pixel size 30 μm

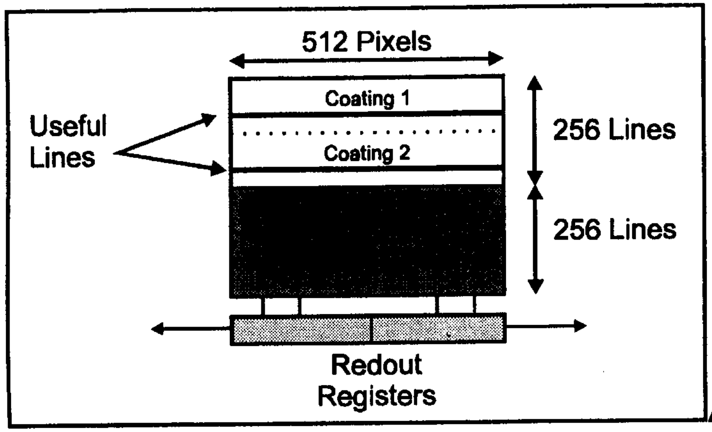
For VIS and NIR bands the Silicon is the typical detector material. Both linear and area CCD arrays of 512 (or 512xN) pixels are a mature technology for many manufacturers. Two configurations have been considered:

◊ Use of two lines of the same area array

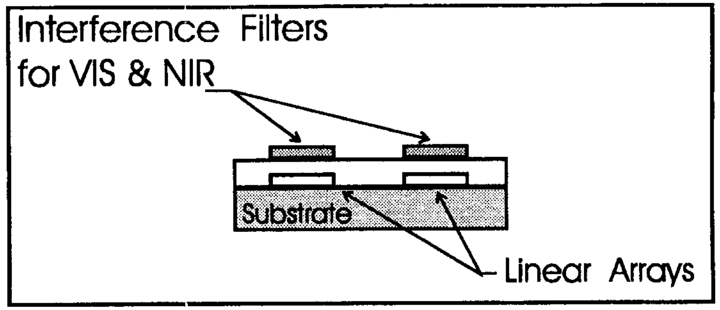
◊ Use of two linear arrays in the same focal plane

For the SWIR channel an InGaAs linear array has been chosen. The advantage over other materials is that it can operate close to room temperature (5 °C).

In TIR region the selected material is still the HgCdTe.
A FPA solution similar to VNIR is envisaged, with two parallel linear arrays integrated in the same package. Linear arrays of 500 pixels are a mature technology and the integration of linear arrays, side by side, can be provided.



Area Array for VNIR



VNIR CCD Scheme

RADIOMETRIC ANALYSIS

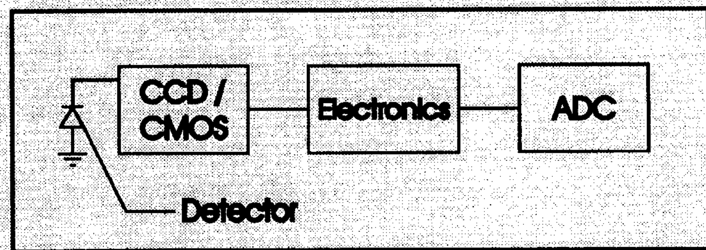
The radiometric performances have been analysed via a computer model, developed by Officine Galileo.
This software allows to calculate the radiometric performances in terms of **SNR in VNIR / SWIR** regions and in terms of **Noise Equivalent Temperature difference (NEdT) in TIR** region.
The main model's outputs are:

- Radiometric resolution (RR), where the noise is considered among the pixels of the same image's column (along track)

- Relative spatial accuracy (RSA) where the noise is considered among the pixels of the same image's row (across track)
- Absolute accuracy (AA) where only the calibration errors are taken into account

These figures are function of system parameters ⇒ spatial sampling interval, orbit altitude, spectral bands, pupil diameter, optics and atmospheric transmittance, clouds albedo for VNIR / SWIR and clouds temperature for TIR.

The model computes signal and noise assuming this detection scheme, adding quadratically the different noise contributions of each block.



Results for VNIR/SWIR

The integration time Ti, required to get the saturation, at maximum of dynamic range (albedo=1.1) has been calculated vs pupil diameter.

With $SSI = 600\ m \Rightarrow T_i\ max = 85\ ms$

Only very small aperture diameters D_r (1-2 mm for VNIR and 4 mm for SWIR) allow the use of this time interval.
Higher D_r can be used reducing the integration time.

VNIR / SWIR Radiometric Parameters

Bands	D_r (mm)	F#	Ti (ms)
B1 - VIS	4.3	2.5	10
B2 - NIR	4.3	2.5	15
B3 - SWIR	10	2.5	15
Assumption : SSI = 600 m			

SNR for $F_{\#}$ =2.5 and albedo = 1

	ESA Specs.	VIS	NIR	SWIR
RR	200	1111	1062	2824
RSA	200	273	265	284
AA	10 %	ca 5 %	ca 5 %	ca 5 %

Results for TIR

Also for TIR the saturation, due to high photon flux, has to be taken into account.

TIR Radiometric Parameters

Bands	D_r (mm)	F#	Ti (ms)
B4 - TIR1	10	2.5	1
B5 - TIR2	10	2.5	0.4
Assumption : SSI = 600 m			

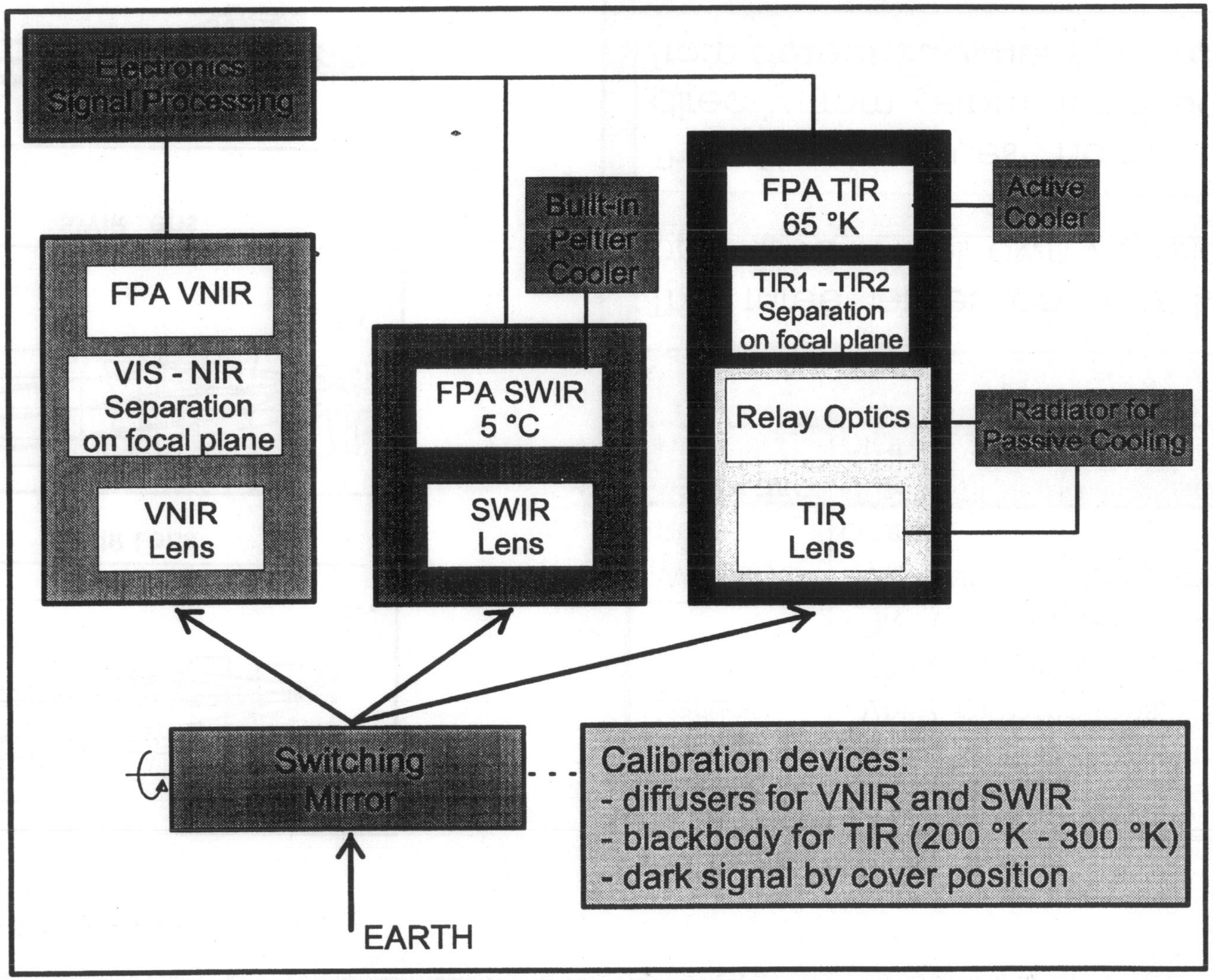
An improvement of the NEdT of a single acquisition can be achieved with an oversampling within the interval of 85 ms.

Radiometric performances at nominal radiance (T_S = 300 K) in K with oversampling

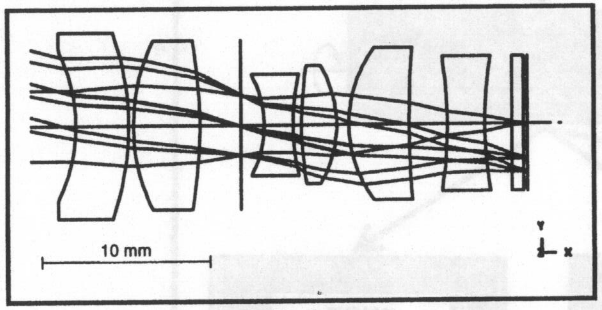
	ESA Specs.	TIR 1 (63 samples)	TIR 2 (122 samples)
RR	0.25	0.12	0.21
RSA	0.25	0.13	0.25
AA	1	0.13	0.17

The value of dark current and dark current drift have been calculated considering a detector operating **T= 65 K** because higher values bring to radiometric performances out of the specifications ⇒ **Need for a cryocooler**.

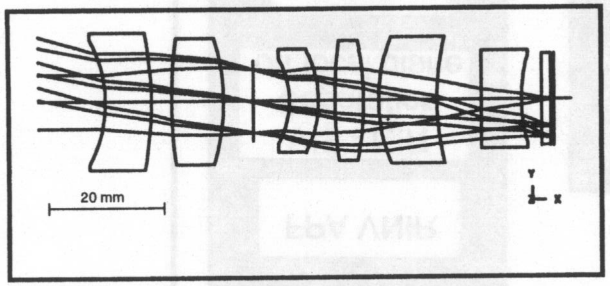
INSTRUMENT BLOCK DIAGRAM



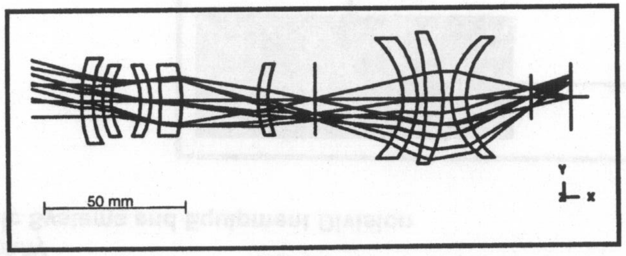
OPTICAL DESIGN



VNIR Lens



SWIR Lens



TIR Lens

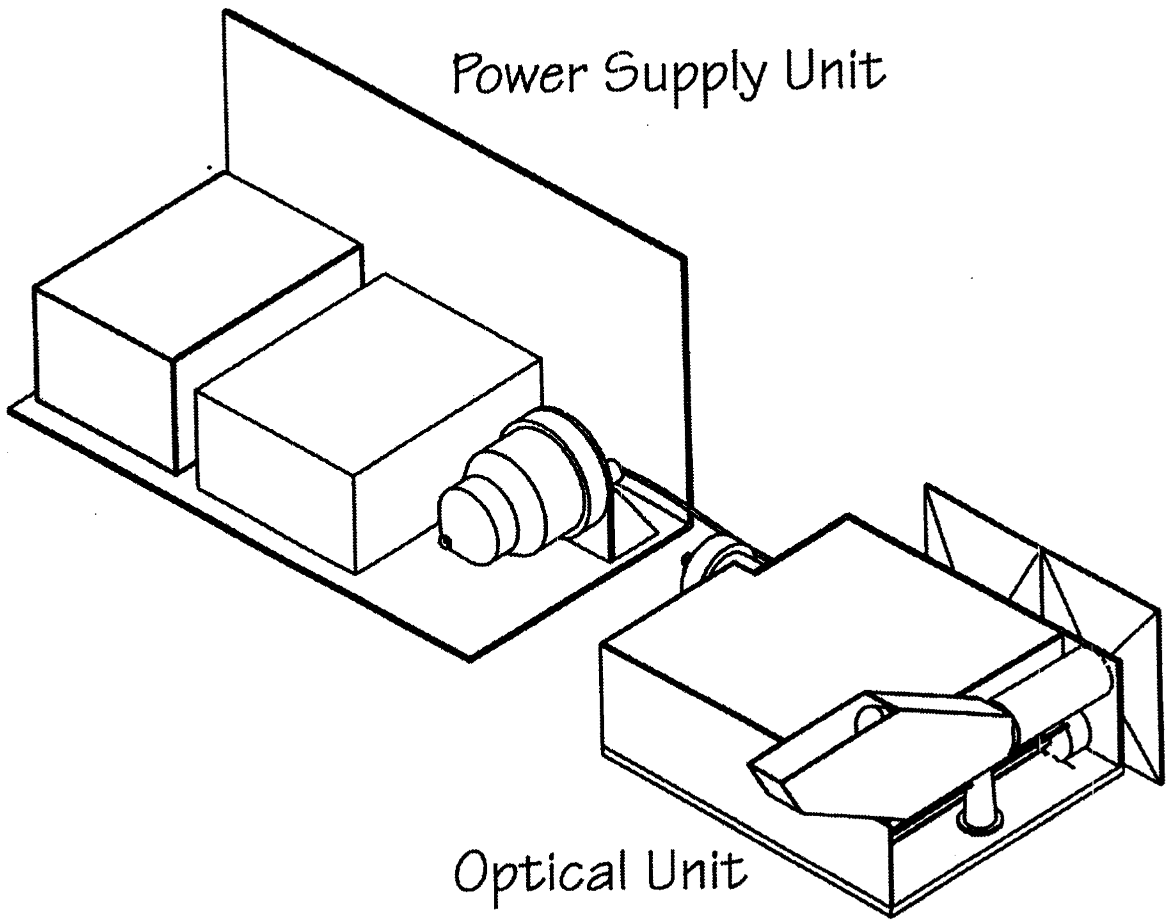
Optics	
FOV	32° ⇒ Swath = 287 km
Lenses	- VNIR: dioptric lens, F = 10.8 mm, F# = 2.5 - SWIR: dioptric lens, F= 25 mm, F# = 2.5 - TIR : dioptric lens, F = 25 mm, F# = 2.5
Wavebands separation	- VIS / NIR : in-field separation on focal plane - TIR1 / TIR2: in-field separation on focal plane

The three lenses are dioptrics objectives optimized in their own wavelength range.

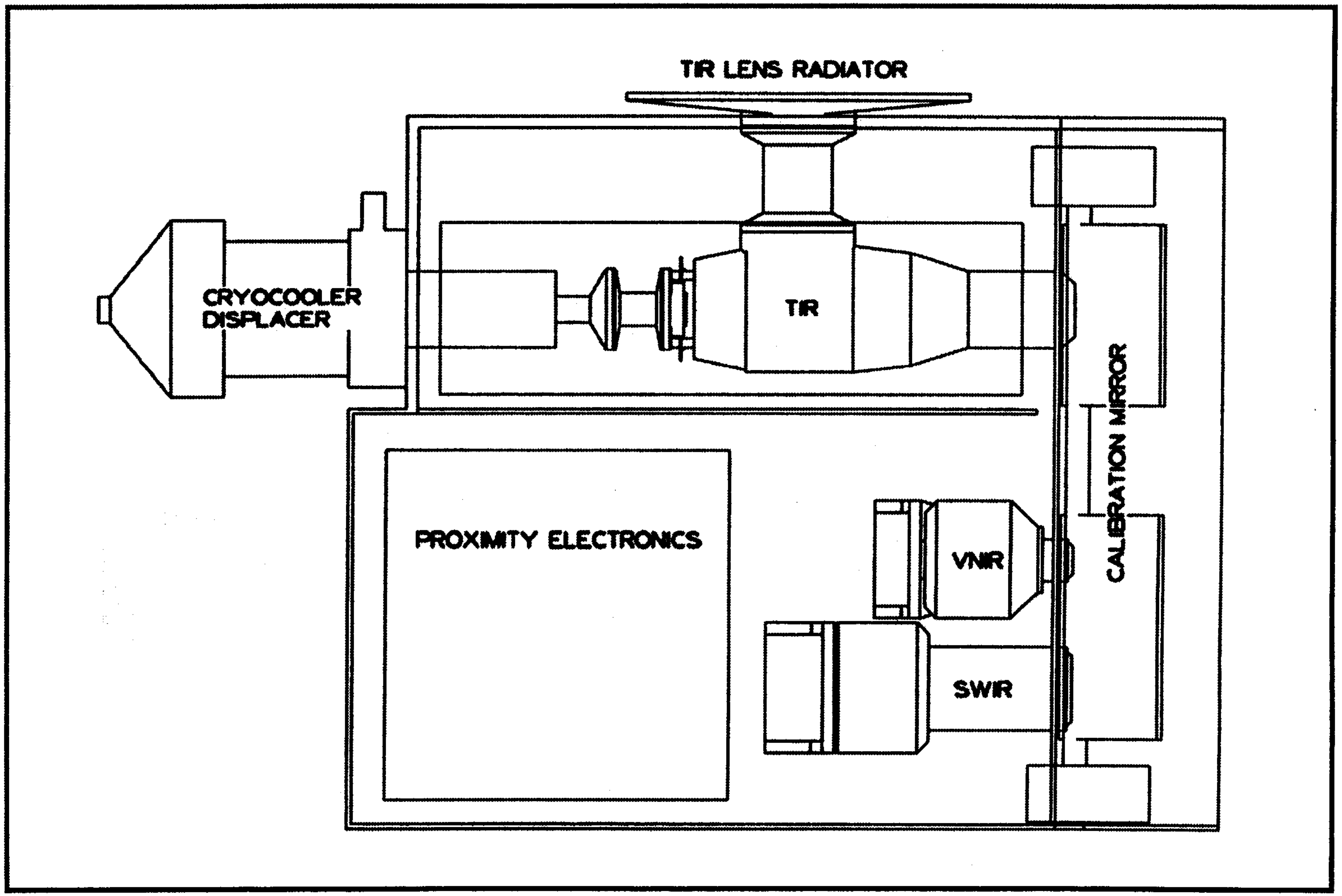
The focal values have been derived directly from geometrical parameters and from detectors dimensional characteristics.

The aperture diameters have been assumed those required to meet the radiometric requirements since the lenses are quasi-diffraction limited systems.

CLOUD IMAGER ASSEMBLY


Power Supply Unit
Optical Unit

OPTICAL UNIT



DIMENSION $\approx$ 380 X 310 X 130 mm

UNCOOLED FPA (TIR) OPTION

- One of the drawback of the described design is the need of the cryocooler. Its high power consumption, cost (for a space qualified product), weight, presence of vibration, could set severe limits to a compact, light, low power consumption instrument.

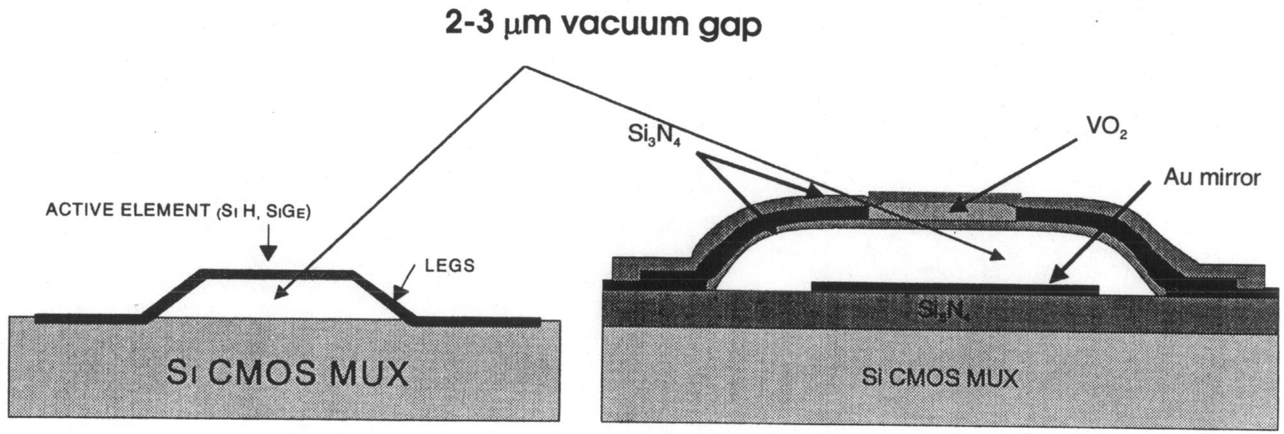
- In recent years the availability of uncooled detectors for the Thermal IR bands, based on arrays of thermal detectors and, in particular, on bolometric type, has suggested to investigate these new devices and their application to space TIR imagers for Earth Observation purposes.

- The activities of this study phase has been performed having the National Institute of Optics / Institute National d'optique - Quebec City, Canada (INO/NOI) as consultant.

- The second phase of this work is then the result of the coordinated activity between OG and INO/NOI.

MICROBOLOMETERS ARRAYS

HIGH SENSITIVITY ⟶ HIGH INSULATION W.R.T. SUBSTRATE ⟶ MICROBRIDGE STRUCTURE

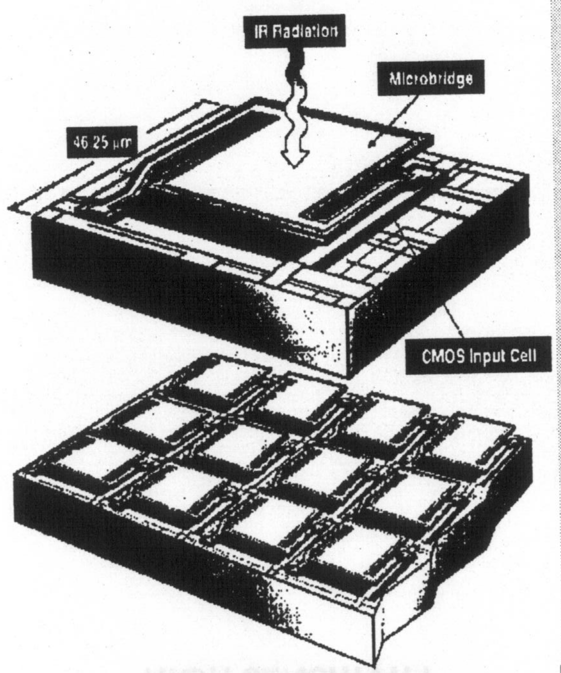


LETI-LIR / SOFRADIR (F)
IMEC (B)

BOEING (USA)
LOCKHEED-MARTIN (USA)
SBRC (USA)
INO/NOI (CANADA)

PIXEL DIMENSION: 50 μm
FORMAT: 320 X 240

Unit Cell Design



MODELLING OF MICROBOLOMETER

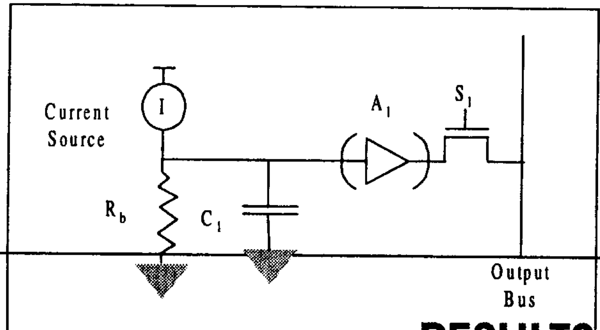
- A computer model calculating the responsivity and noise of microbolometers arrays has been developed and validate with respect to existing devices.

- Simulation have been performed, together with INO/NOI, to evaluate the performances of μBs arrays designed for the CLOUD IMAGER application.

Assumptions

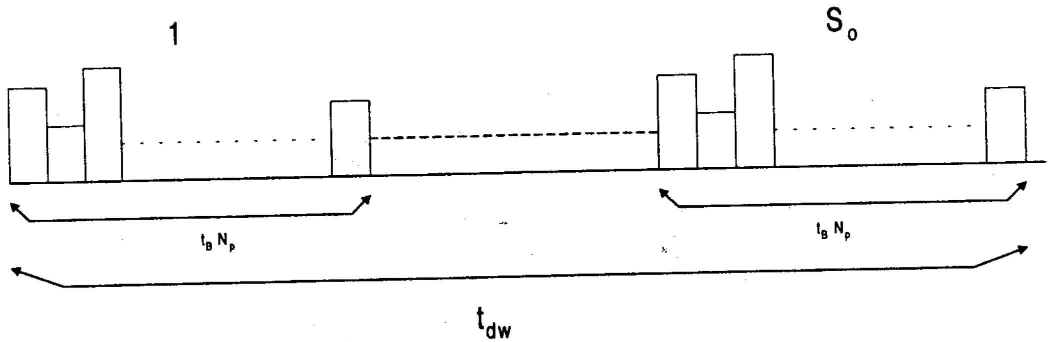
- Linear array 256 pixel 60 μm x 60 μm

(SSI < 1000m Swath 150 - 300 Km)



Max filter bandwidth ≈ 5 kHz
(due to largest capacitor we can implement on chip)
From that the oversampling, can be used. It is the multiple acquisition during the dwell time (85 ms); then the samples can be averaged at on board processing level.

RESULTS OF INO/NOI SIMULATION



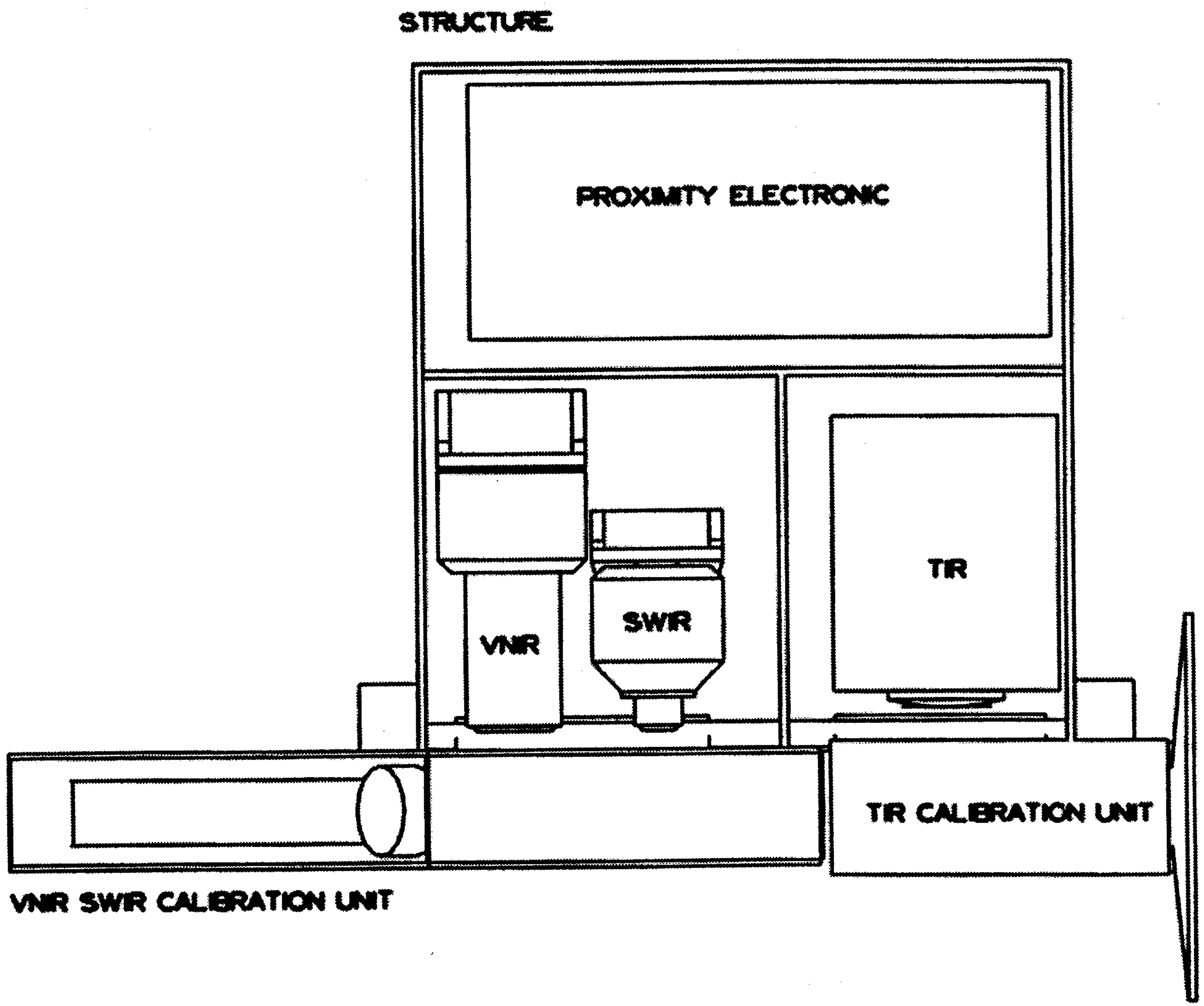
S_0 = number of samples during the dwell time.
Pulse bias is used to get higher rsponsivity.
We need a trade-off between the filter bandwidth and the number of samples.

Suggested baseline (Pulsed bias no oversamplig)

IR Band	Die Width (mm)	Over Samp I	t_{ther} (ms)	Absorp	NEP_S (10^{-10} watts)	***ESA Specs. (K)***	NEdT (K)
4	7	1	49.6	0.24	0.434	0.25	0.256
5	7	1	8.9	0.81	0.152	0.25	0.049

- Smaller die than using a DC bias.
- Less processing of data
- Slanting of the image due to satellite motion (the pixels are read sequentially)
- NEdT can be reduced by using N parallel lines of pixel and a digital TDI at process level

OPTICAL UNIT LAYOUT


STRUCTURE
PROXIMITY ELECTRONIC
VNIR
SWIR
TIR
TIR CALIBRATION UNIT
VNIR SWIR CALIBRATION UNIT

POWER AND MASS BUDGET

Mass (gr)

	Coooled TIR FPA	Uncooled TIR FPA
OPTICAL HEAD	11400	10100
ELECTRONIC BOX +cryocooler for MCT FPA option	15400	1900
Total	26800	12000

Power (Watt)

	Coooled TIR FPA	Uncooled TIR FPA
OPTICAL HEAD	16	25
ELECTRONIC BOX +cryocooler for MCT FPA option	64	20

Total	80	45

CONCLUSIONS

The study showed that the hypothesis to utilize a pushbroom concept for the Cloud Imager presents some interesting features:

- The opto-mechanical system has quite compact dimensions and all the main elements can be placed on the same optical bench.

- The radiometric analysis, shows that the solution using both cooled or uncooled FPA can meet the radiometric requirements in all five bands.
(The VNIR/SWIR channels are the same in both solutions)

- The TIR uncooled FPA solution is, clearly, the most attractive even if some critical point, such as thermal control of FPA, must be deeply investigate in the next study phase to clarify the feasibility of an uncooled CLOUD IMAGER.

III. TECHNOLOGY AND SUPPORT
C. PASSIVE SENSOR CONCEPTS AND TECHNOLOGIES

BROADBAND RADIOMETER

R. MERCIER YTHIER, REOSC

BBR

REOSC Groupe sfim

I BBR main specifications

II Results of the trade-off studies

III Instrument description

IV Main performances

V Critical points review

BBR Main requirements

2 spectral channels :

- ✓ Short Wave [0.2 , 4 µm]
- ✓ Long Wave [4 , 50 µm]

Swath : 120 km, across track

Pixel number : 5

Radiometric requirements :

- ✓ Resolution : 0.5 $W/m^2/sr$
- ✓ Absolute accuracy : 1.5 $W/m^2/sr$

Results of the trade-off studies

REOSC Groupe sfim

The main design constraints are :

- ✓ the necessity of in-flight calibration
- ✓ the limitation of the number of mechanisms in order to minimize the overall cost
- ✓ the limitation of the complexity of the optical design in order to obtain good radiometric performances

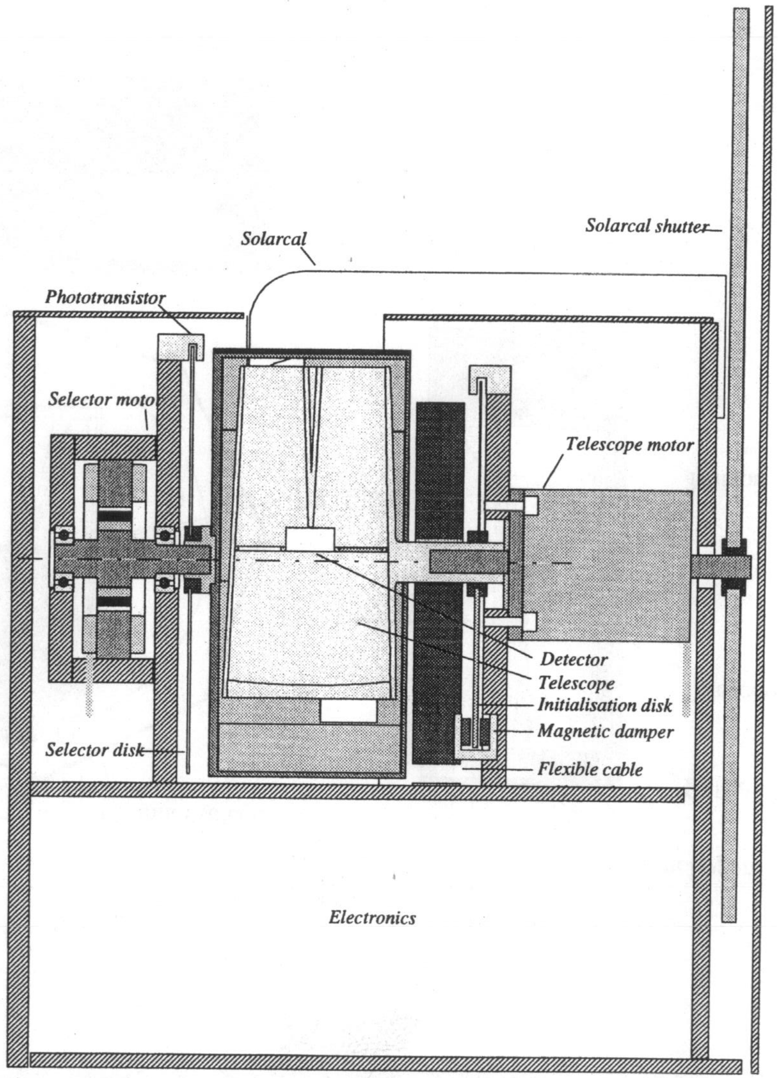
Results of the trade-off studies

REOSC
Groupe sfim

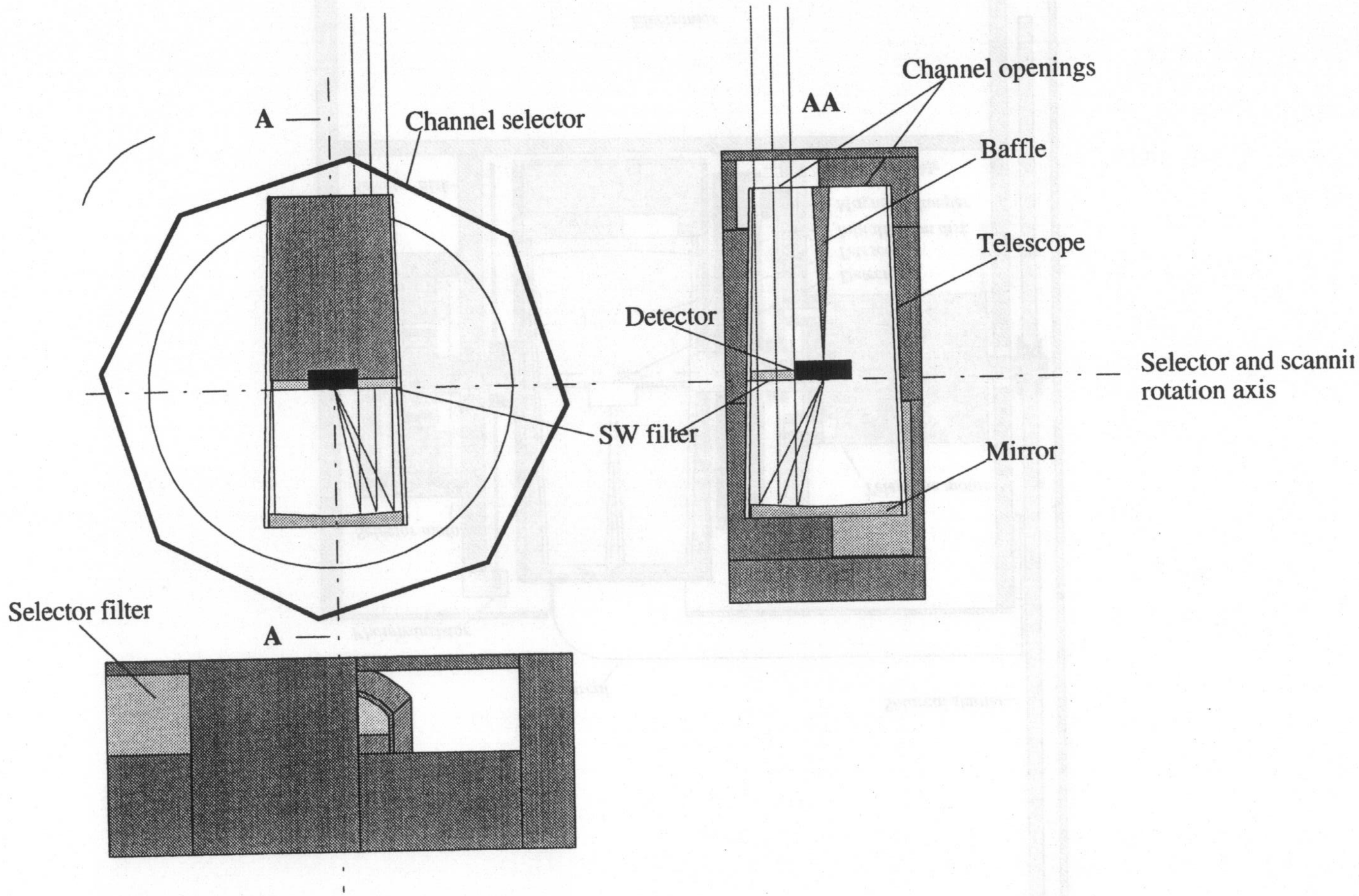
The trade-off studies have led to the following design :

- ✓ scanning radiometer
- ✓ Multiplexed spectral bands (same telescope for both bands)
- ✓ LW radiance ([4 ; 50 µm]) obtained by subtracting the SW to the total radiance
- ✓ In-flight calibration using a Black Body Simulator (BBS) and Solar Diffusers (Solarcal)

Instrument description



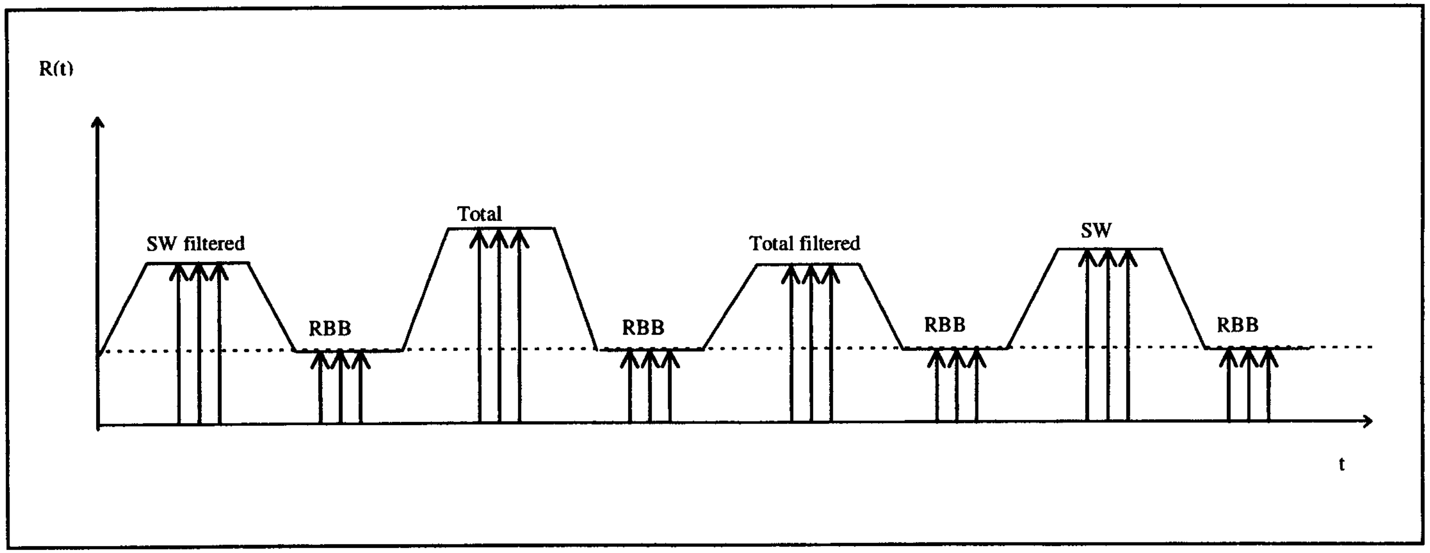
Channel Selection



Radiance measurement

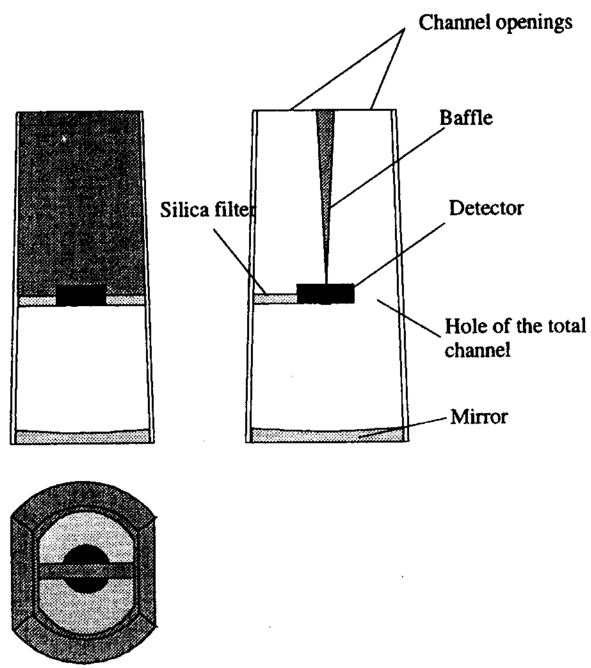
REOSC Groupe sfim

- Use of a pyroelectric detector
- Alternation of scene sights and sights of the back face of the selector (RBB sight)
- Alternation of channel sights



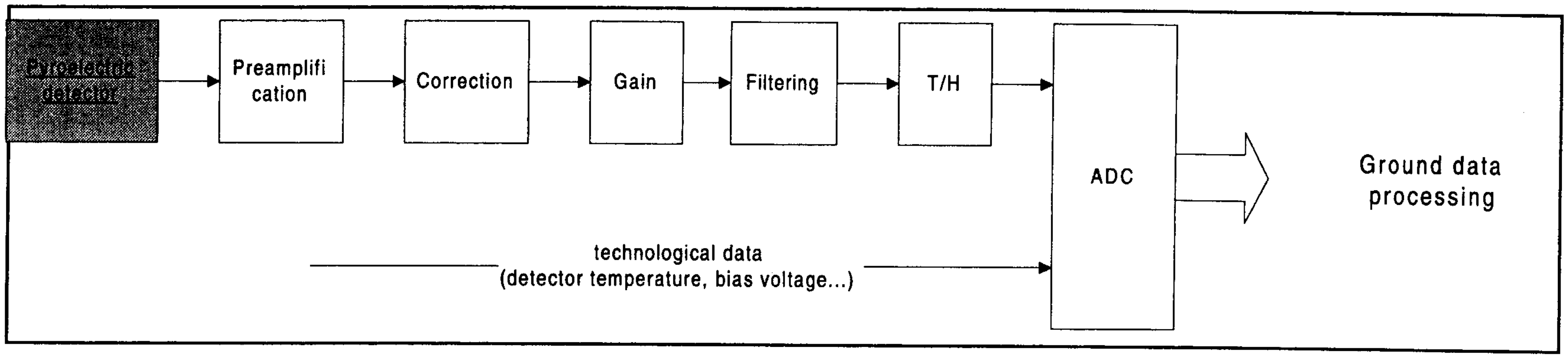
Instrument description

- pyroelectric detector, without window, 3X3 mm^2
- parabolic mirror f=28.1 mm, ϕ 28.1 mm
- silica filter for the SW channel



Detection electronics

- Same overall architecture as ScaRaB/Meteor
- Bandwidth : [0.1 ; 300 HZ]
- f_{pixel} : 8 Hz
- NEP = 0.035 $W/m^2/sr$



Channel selector

REOSC Groupe sfim

- rotation speed : 8 Hz
- motion independent on the scanning mechanism
- selector position error < 1/1000 turn
- position detected thanks to a disk with 8 holes fixed on the selector and a photodiode transistor
- synchronisation of the motion with a reference clock using a phase locked loop
- self commutated synchronous motor, with permanent magnet at the rotor
- same bearings as the choppers of ScaRaB/Meteor, dry lubricant : MoS_2, preload : 75 N, friction torque : 1 mN.m
- no launch locking device

Calibration strategy

REOSC Groupe sfim

In-flight calibration includes :

- ✓ space sight to subtract offset and determine the RBB radiance,
- ✓ BBS sight to determine the non spectral gain of the instrument,
- ✓ Solar sight to monitor spectral drifts,
- ✓ Cross-calibration of the two channels in sighting a SW scene through the selector filters

On-ground calibration includes :

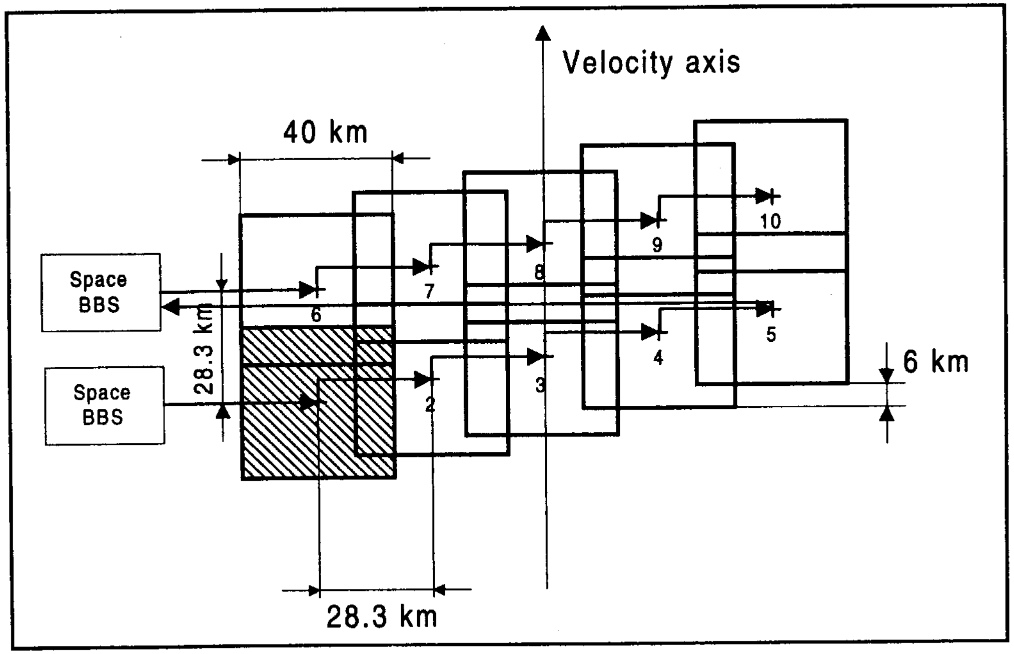
- ✓ BBR spectral response,
- ✓ BBS calibration.

Pixel scanning

Scan period : 4.06 s

Pixels number : 5

Stop duration for each pixel : 0.377 s

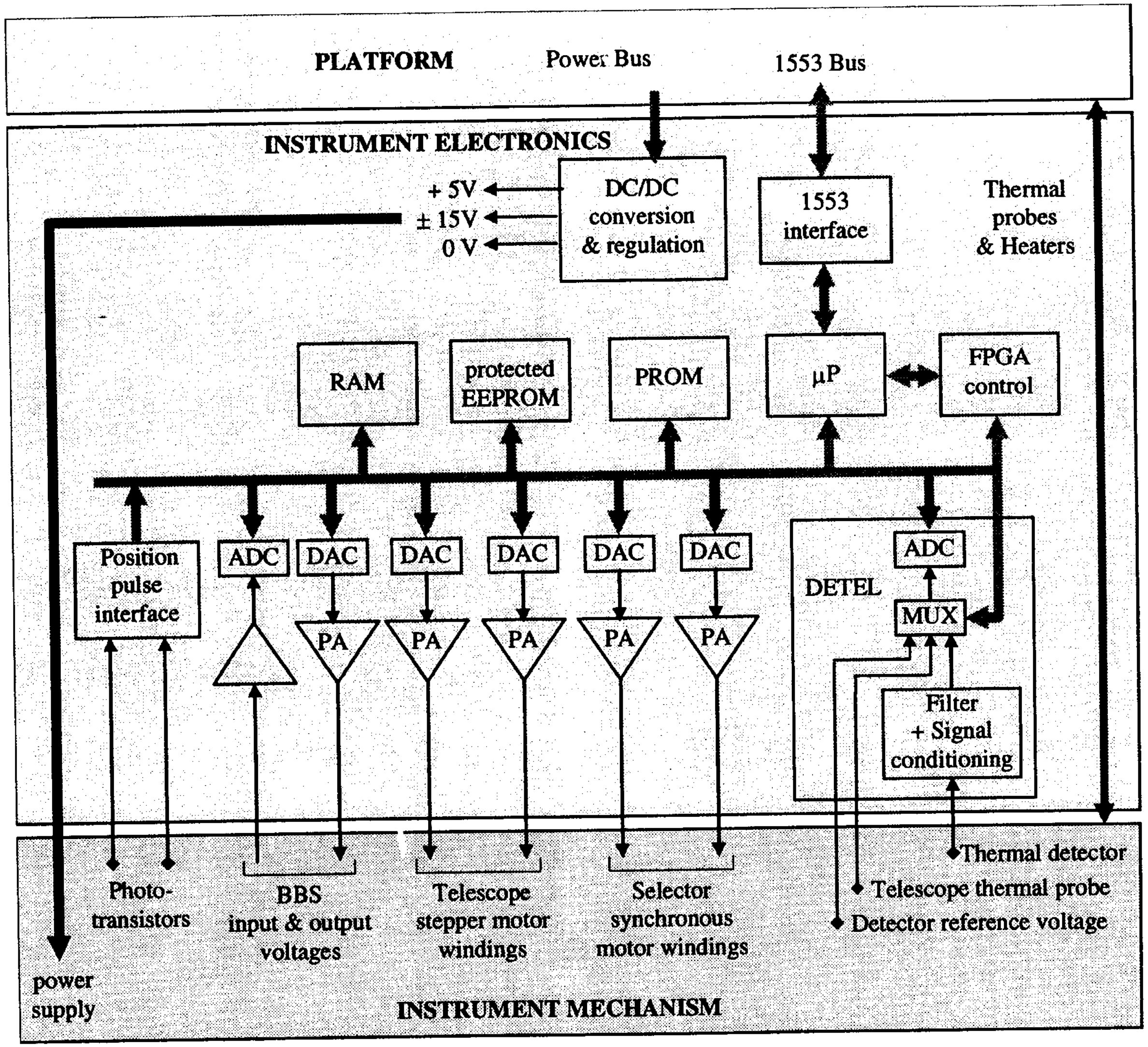


Scanning mechanism

REOSC
Groupe sfim

- stepper motor (400 steps)
- same ball bearings as the chopper of ScaRaB/Meteor
- bearings preload : 50 N
- step duration : 1/128 s
- average speed between two steps : 20 tr/mn
- stabilisation error < 1 mrad (500 m on-ground)
- mechanism initialisation involving a phototransistor device
- mechanism lifetime estimation > 10 years
- no launch locking device

Instrument electronics



Geometrical performances

REOSC Groupe sfim

Pointing accuracy

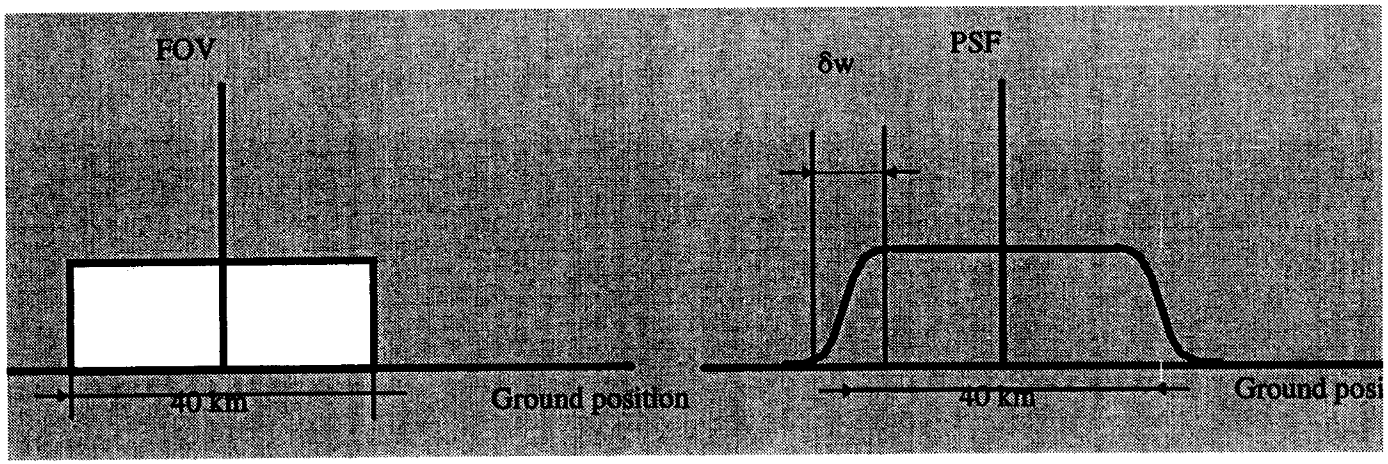
Budget	1.5 km
☞ misalignment of the telescope with respect to the interface with satellite reference frame	0.35 km
☞ scanning accuracy	1 km

Co-registration

- easily met because of multiplexing

Optical performances

FOV and PSF



Main sources of degradation

- Geometric aberrations
- diffraction
- Stray light
- Trailing

Optical performances

	δw
Aberrations	4 mrad
Diffraction	0.03 mrad (@ 500 nm)
Stray light	negligible
Trailing	6 mrad
Budget	7.2 mrad

Radiometric performances

REOSC Groupe sfim

Requirements

Radiometric resolution	$< 0.5\ W.m^{-2}.sr^{-1}$
Absolute accuracy	$< 1.5\ W.m^{-2}.sr^{-1}$

Radiometric resolution is the *instrument noise* (random errors which could be averaged)

Absolute accuracy is the sum of *unknown offset* with *gain error* (proportional to the input radiance)

Radiometric resolution

REOSC Groupe sfim

Noise errors are detection electronic noise. The main sources are :

- ✓ dielectric noise
- ✓ amplifier noise
- ✓ thermal noise
- ✓ Current and Johnson noise
- ✓ 1/f noise
- ✓ Quantization noise

Absolute accuracy

REOSC Groupe sfim

Unknown offsets are :

- ✓ cross talk between channels due to the detection chain
- ✓ stray light
- ✓ RBB temperature variations
- ✓ thermal leak of the SW filter
- ✓ cross calibration errors

Gain errors are

- ✓ spectral drift of the instrument
- ✓ knowledge of the instrument gain

SW estimated performances

Contributor	scene 1	scene 2	scene 3
Gain error (3σ)	1.48 %	1.53 %	1.60 %
Residual Offset (3σ)	0.32 $W.m^{-2}.sr^{-1}$	0.32 $W.m^{-2}.sr^{-1}$	0.32 $W.m^{-2}.sr^{-1}$
Noise errors (3σ)	0.10 $W.m^{-2}.sr^{-1}$	0.10 $W.m^{-2}.sr^{-1}$	0.10 $W.m^{-2}.sr^{-1}$

Scene 1 is ocean with thick clouds

Scene 2 is ocean with thin clouds

Scene 3 is desert with thin and high clouds

LW estimated performances

Contributor	LW scene
Gain error (3σ)	1.05 %
Noise errors (3σ)	0.14 $W.m^{-2}.sr^{-1}$

SW radiance	0 $W.m^{-2}.sr^{-1}$	100 $W.m^{-2}.sr^{-1}$	200 $W.m^{-2}.sr^{-1}$	370 $W.m^{-2}.sr^{-1}$
Offset (3σ)	0.18 $W.m^{-2}.sr^{-1}$	0.3 $W.m^{-2}.sr^{-1}$	0.42 $W.m^{-2}.sr^{-1}$	0.62 $W.m^{-2}.sr^{-1}$

III. Main interface characteristics

REOSC Groupe sfim

- Estimated mass : about 6 kg
- Volume : 260 X 210 X170
- Power consumption : 20 W rms
- Data rate : < 5 kbauds
- Telescope reaction torque : < 50 mN.m
- Selector kinetic momentum : 0.01 mN.m

IV. THE PLANS

EARTH EXPLORER EARTH RADIATION MISSION, PHASE A ACTIVITY PLAN

A. TOBIAS, ESA, EOPP

IV. THE PLANS: THE ERM PHASE A ACTIVITY PLAN

1- The Explorer mission selection mechanism
2- The Explorer mission selection criteria
3 - The full reference plan
4 - The Phase A activities
  4.1 Mission definition
  4.2 System definition
  4.3 Technology and support
5. Overall phase A plan

1. THE EXPLORER MISSION SELECTION MECHANISM

- A four step selection mechanism is established for the core Earth Explorer missions:

Step	Contents	
1	Call for ideas and selection for step 2	ESAC
2	Assessment studies and selection for step 3	ESAC/PB-EO
>>> 3	**Phase A studies and selection for step 4**	ESAC/PB-EO
4	Implementation (B, C, D, E)	

- Step 1, was completed in 1994 - 1995 >> Nine candidate mission concepts
- Step 2, was completed in 1995 - 1996 >> Reports for Assessment, Granada ...
- Step 3 is ongoing, selection for transition to step 4 expected second half 1999.

2. THE EXPLORER MISSION SELECTION CRITERIA

- Seven selection criteria agreed for application at each step transition:

1. Relevance to the research objectives of the Earth Explorer

2. Need, usefulness and excellence

3. Uniqueness and complementarity

4. Degree of innovation and contribution to the advancement of European Earth Observation capabilities

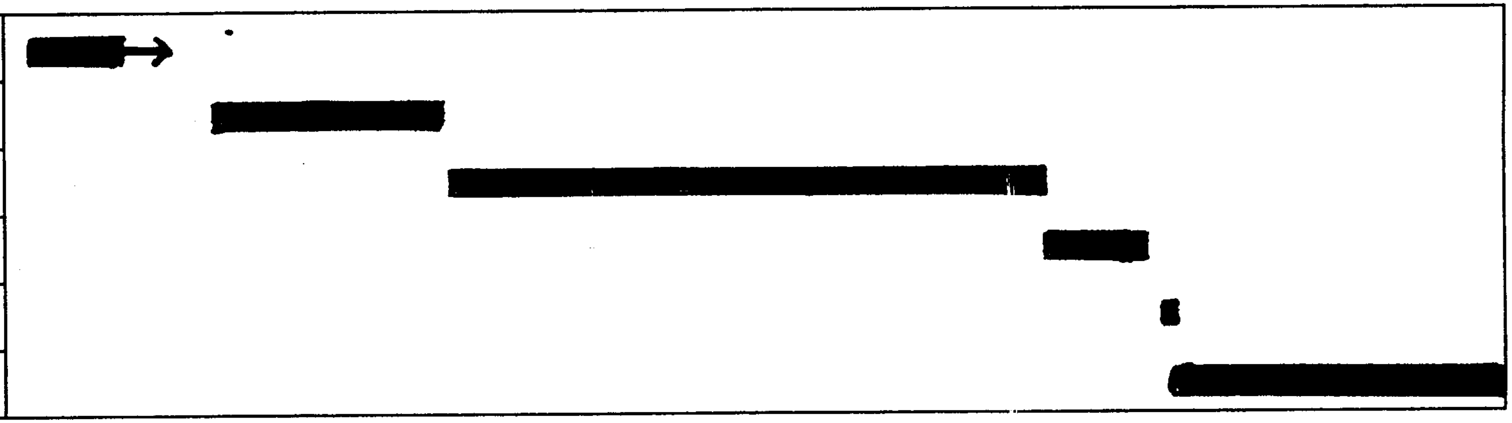
5. Feasibility and level of maturity

6. Timeliness

7. Programmatics

3. THE FULL REFERENCE PLAN

PROJECT PHASE	YEAR							
	1999	2000	2001	2002	2003	2004	2005	2006
Phase A								
Phase B								
Phase C/D								
Margin/launch camp.								
Launch								
Operations								



EOPP	Earth Observation Envelope Programme - Explorer Component

4. THE PHASE A ACTIVITIES

- Phase A activities are defined to enable the planned future:
  - Selection after phase A, two out of the four candidates according to established selection criteria
  - Implementation, phase B, C, D, E - Earth Observation Envelope Programme
  - Reference launch date: January 2005 - Science operations: two years

- Three main activity groups:.

  1- Mission definition activities: establishment of requirements and estimation of mission performance
  >> Mission Advisory Group
  >> Scientific studies
  >> Campaigns

  2- System analysis and definition: phase A system study

  3- Technology and support: key elements of mission architecture

- Activities carried out with scientific institues and industry

4.1. THE PHASE A ACTIVITIES - Mission definition

- Mission Advisory Group
- Generates Mission Requirements Document: objectives, requirements, data processing, etc.
- Advices on scientific studies and campaigns and on suitability of system options

- Scientific studies

	Contractor	Reference
Synergy of ERM observations	MPBT	12068/96
Analysis of CLARA (Dutch Cloud and Radiation campaign) data	KNMI	12953/98
Quantification of synergy	Univ.Reading	starting
Impact of ERM observations on NWP	ECWMF	starting

The ongoing and starting scientific studies address the "synergetic" aspects of the ERM. Observation synergy is a critical point but at the same time the scientific strength and uniqueness of ERM compared to other mission concepts.

A study also address explicitly immediate usefulness.

- Campaigns
- CLARE: Campaign led by the University of Readings with EOPP support

4.2. THE PHASE A ACTIVITIES: System definition - The Phase A system study

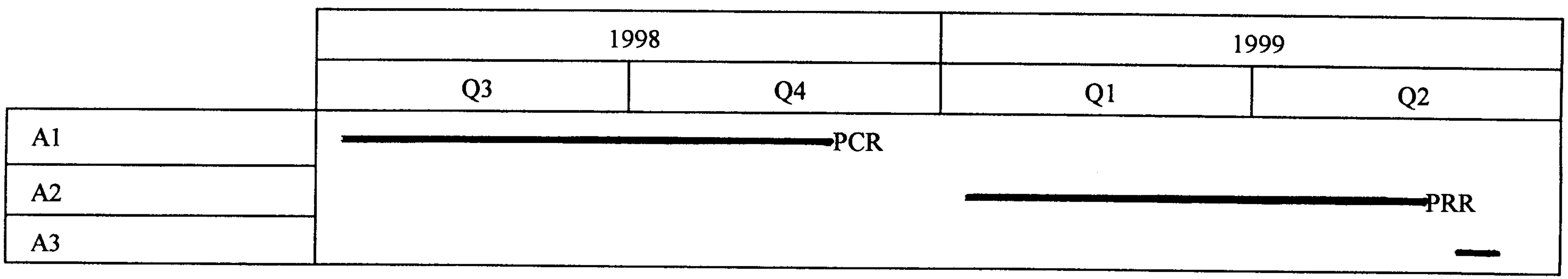
- **End-to-end system study**, space segment (platform, instruments, satellite) and ground segment (command and data acquisition, mission operations and satellite control, processing and archiving) and operations concepts,

- Three natural steps separated by two review points (also according to ECSS)

- **A1: Option identification and trade-off**
  - Analysis of requirements, identification of sytem options, preliminary concepts, trade-off
  >> **PCR**: Preliminary Concept Review: System baseline selection

- **A2: Detailed definition of baseline**
  - To the level required to assess misison performance and system costing
  >> **PRR**: Preliminary Requirements Review: tuning mission - system, agreement for costing

- **A3: Consolidation and detailed costing**



4.3. THE PHASE A ACTIVITIES: Technology and support

- Address critical elements. ESA Earth Observation and technology programmes and national intiatives

Reusability of ground segment	MMS-F
ATLID development	MMS-F
Lidar signal retrieval under low SNR conditions (2x)	TNO, Univ. of Geneve
Cloud Profiling Radar breadboard	Alenia Difesa
CPR, LNA development	Yllinen
CPR, EIK prequalification	CPI
CPR, Upconverter development	TBD
CPR, optimisation	TBD
Cloud imager concepts (including uncooled concepts) for ERM	Alenia Difesa
Broadband radiometer concepts for ERM	REOSC

- Known national European activities (mainly in France) also followed.

5. OVERALL PHASE A PLANNING

ERM