ERICC

Evolution and Radiative Impact of Contrail Cirrus

Outline

Summer School Alpbach 2010
"New Space Missions for Understanding Climate Change"
July 27 - August 5, Alpbach/Tyrol - Austria

1. Introduction and Context

The major impact that cirrus clouds have on current and future climate has been recognized for some considerable time

(Liou, 1986; Baran, 2005)

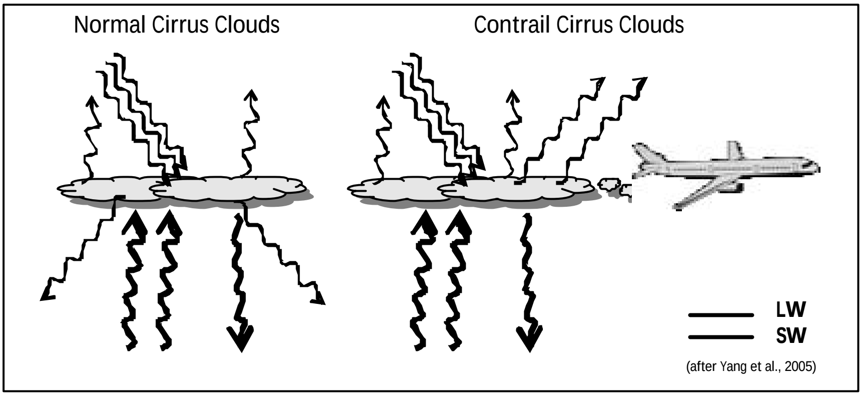
1. Introduction and Context

A key uncertainty in our knowledge of cirrus clouds is the significance of contrail cirrus

(Yang et al., 2005)

- contrails are linear clouds, form from the mixing of atmosphere and jet exhaust
- Injection of H_2O, CO_2, NO_x, H_2SO_4 and soot
- Aerosol acts as ice nuclei
- Particular environmental conditions necessary

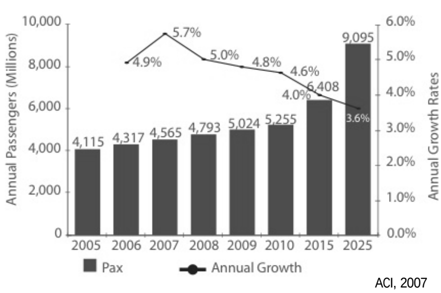
1. Introduction and Context



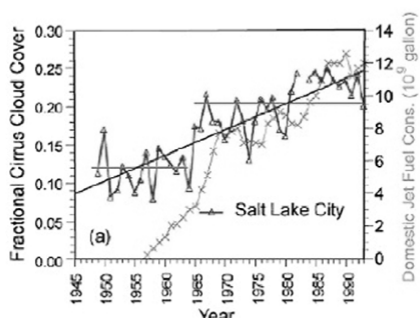
There is still uncertainty about the precise climate impact of cirrus clouds

Growth in air traffic

Increasing global air traffic suggests the influence of contrails will only become more significant in future



ACI, 2007



Yang et al., 2010

1. Introduction and Context

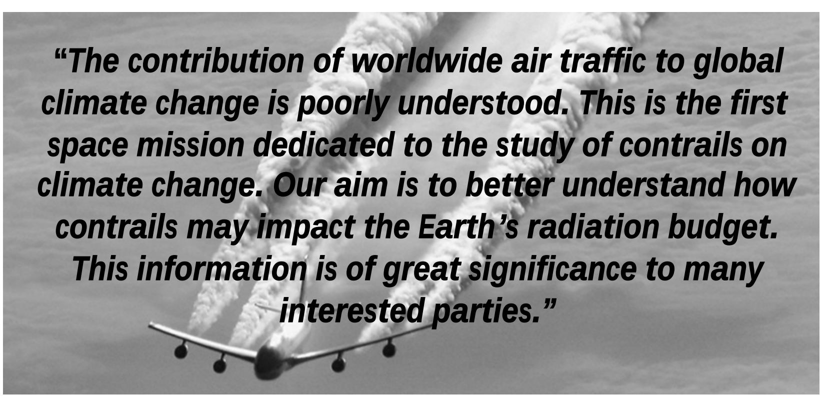
A recent review identifies the current targets of contrail climate science

- Greater use of satellite technologies
- Studies over longer durations and larger areal scales
- Better constraint on

  - contrail coverage
  - evolution of contrail → cirrus
  - cloud optical properties
  - radiative forcing potential

(Yang et al., 2005)

2. Mission Statement



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3. Science Objectives

I) To better constrain the amount of contrails generated by air traffic

II) To observe the evolution of contrails → contrail cirrus

III) To constrain the radiative impact of contrails and contrail cirrus

3. Science Objectives

I) To better constrain the amount of contrails generated by air traffic

Requirement :
To identify and survey Earth's major air corridors and observe the amount of contrails formed

Method:

- Define key air corridors based on global air traffic
- Identify contrails using the Contrail Detection Algorithm (CDA) of Mannstein et al. (1999)

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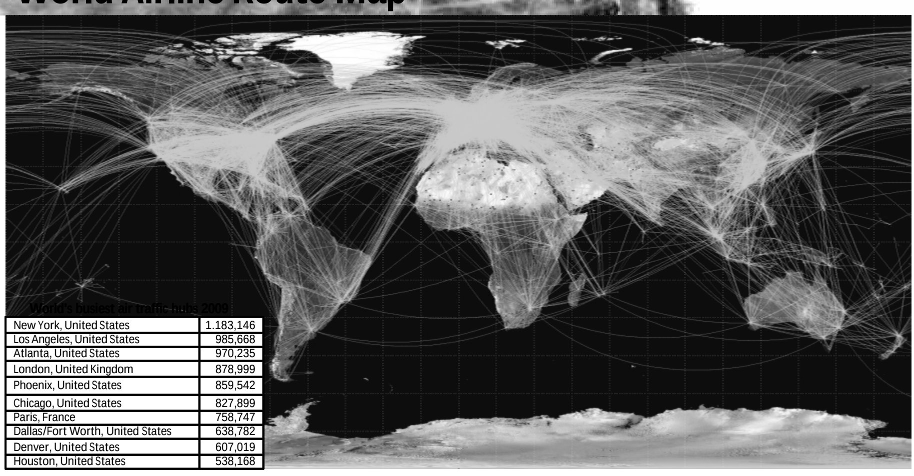
World Airline Route Map



World's busiest air traffic hubs 2009

New York, United States	1.183,146
Los Angeles, United States	985,668
Atlanta, United States	970,235
London, United Kingdom	878,999
Phoenix, United States	859,542
Chicago, United States	827,899
Paris, France	758,747
Dallas/Fort Worth, United States	638,782
Denver, United States	607,019
Houston, United States	538,168

(Wikipedia, 2010)

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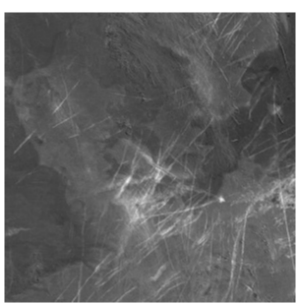
Contrail Detection Algorithm (CDA)



(Mannstein,1999)

AVHRR on NOAA-12, 10.8 μm – 12.0 μm

(Mannstein,1999)

Result of the CDA

- Input data 12.0 μm and 10.8 μm -12.0 μm
- Filtering, normalisation process, deploying gradients
- Applying line filter in 16 directions

✓ Confirmed contrail, when > 10 pixels from contrail and > 16 pixel distance

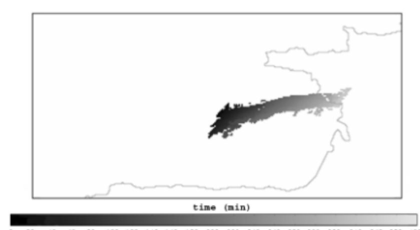
3. Science Objectives

II) To observe the evolution of contrails → contrail cirrus

Requirement 1:
To obtain regular, quality images of the contrails detected using the CDA

Requirement 2:
To gain some insight into the processes involved in contrail evolution

Automatic Contrail Tracking Algorithm (ACTA)



- Using BTD = 10.8 µm - 12.0 µm like CDA
- CDA passes detected contrails to ACTA
- Input: geographical position
  ➔ replotted assuming wind vectors
  at 10 km alt (e.g. modelled by ECMWF)
- Step I succeeds: contrail at t+? t corresponds to the same contrail
- Step II retrieves the contrail-cirrus
- Clustering retrieves the shape by selecting the pixels in group

(M. Vazquez-Navarro et al., 2010)

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3. Science Objectives

II) To observe the evolution of contrails → contrail cirrus

Requirement 1:
To obtain regular, quality images of the contrails detected using the CDA

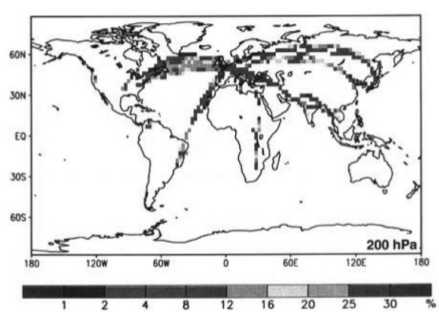
Method:
- Automatic Contrail Tracking Algorithm (ACTA)
- Resolution
  - spatial resolution: 200m
  - temporal resolution: hourly
  - suitable spectral resolution

3. Science Objectives

II) To observe the evolution of contrails → contrail cirrus

Requirement 2:
To gain some insight into the processes involved in contrail evolution

Method:
- get meteorological conditions (esp. RH_i) from meteorological satellite or database (Meteosat,...)
- compare theoretical evolution to our observations



Probablity (%) of ice supersaturation ($Rh_i \geq 100\%$)
(Gierens et al., 2000)

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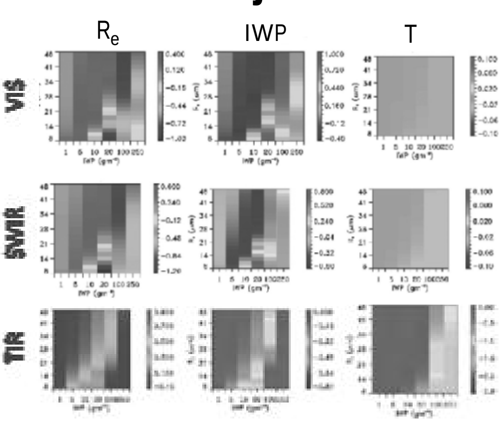
3. Science Objectives

III) To constrain the radiative impact of contrails and contrail cirrus

Requirement :
To recover radiatively important parameters from our measurements

- Optical depth (t), effective particle radius (R_e), ice water path (IWP) ← *all linked*
  cloud height, cloud temperature
- Select bands which are sensitive to these parameters

3. Science Objectives



(Cooper et al., 2006)

- VIS/SWIR very sensitive to:
  IWP, R_e and t
- TIR sensitive to these too, but less so
  - combine with bands
  - VIS/SWIR in day, MIR at night
- Only TIR is sensitive to T;
  and also height

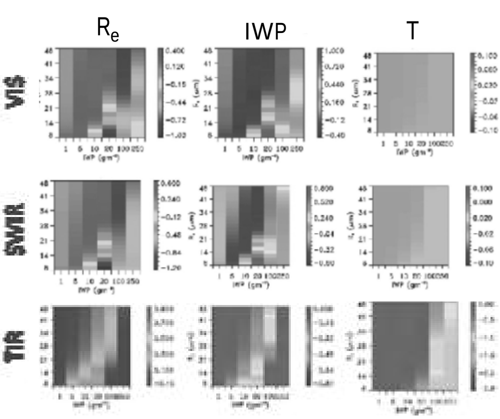
3. Science Objectives

III) To constrain the radiative impact of contrails and contrail cirrus

VIS	SWIR	MIR	TIR	
0.66µm	1.66µm	3.90µm	10.80µm	12.00µm

This is the minimum number of bands necessary to recover the 5 major cloud parameters but it is not sufficient for this mission

3. Science Objectives



(Cooper et al., 2006)

1.38/0.66 → thin cirrus over land

1.38/1.24 → thin cirrus over sea

1.66/0.66 → thick cirrus

1.66 → cirrus over stratocum. stack

1.38/1.23 → aerosol-rich atmosphere

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4. Science Requirements

Spectral and Radiometric Requirements

	VIS	SWIR			MIR	TIR	
Wavelength (µm)	0.66	1.24	1.38	1.66	3.90	10.80	12.00
Bandwidth (FWHM) (µm)	0.02				1.0		
Radiometric Requirements	> 7 bit						

4. Science Requirements

Observational Requirements

Geometry:

- Spatial resolution / ground pixel size = 200 m
- Swath width = 400 km
- Main area coverage: Northern hemisphere

Time coverage:

- Revisit time = hourly during daytime 0900 – 1700 LT, hourly nighttime

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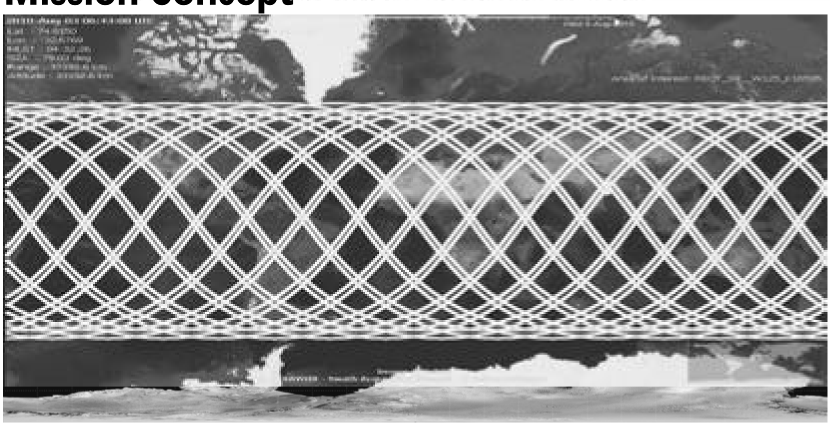
5. Mission Concept

5.1. Orbit

- Constellation of 8 satellites
- Non SSO LEO Orbit
- Inclination i = 60°, altitude h = 566 km, orbit time T = 96 min
- 15 orbits per day → Revisit time of 1 hour for 8 hours
- Angular spacing of ascending nodes of constellation: ?O = 15°
- Drift of the ascension of the right angle: dO/dt = 3.7°/day
- > 330 d/y at least 4 consecutive hrs. of coverage in optimal times

5. Mission Concept



World air-traffic routes vs. orbit

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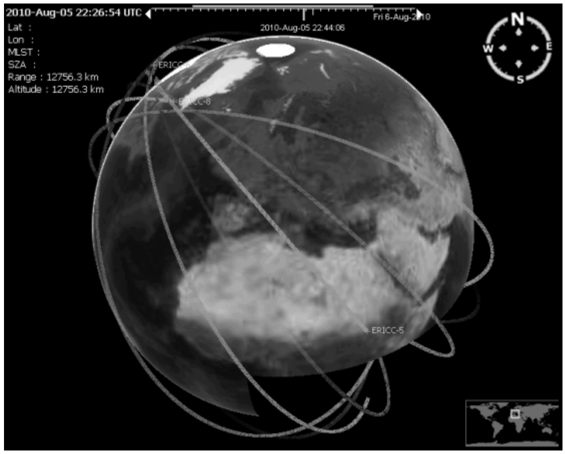
5. Mission Concept



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5. Mission Concept

5.2. Ground Segment


ESA Ground Station Perth

Requirements
- Download capability of 12,5 Gbit/orbit
- Tracking of > 10 orbits per day

Solution
- Two Ground Stations
    - DLR Ground Station Neustrelitz (Germany)
    - ESA Tracking Station Perth (Australia)
- Tracking of 11 orbits /day
- Average contact time per orbit: 7 min
- Download Time for 1 orbit data: 1,5 min

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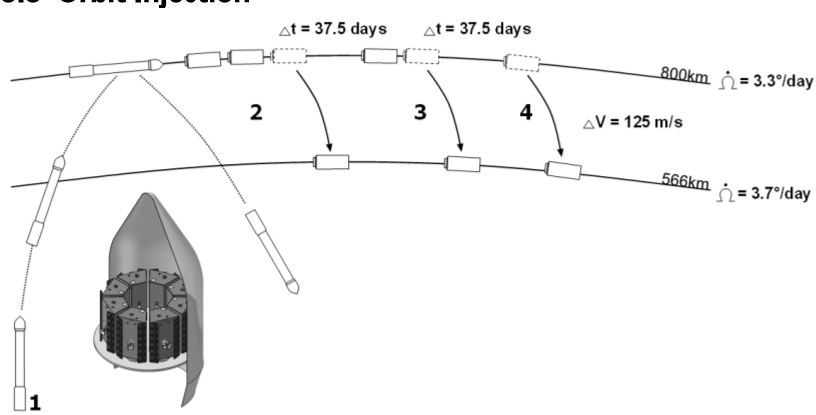
5. Mission Concept

5.3. Launcher Selection

Launcher	Payload (kg) to LEO	Max. Num. Of Satellites	Cost (Million €)
SOYUZ	5200	?	60
DNEPR-1	4500	8	20
PSLV	2200	10	~ 15

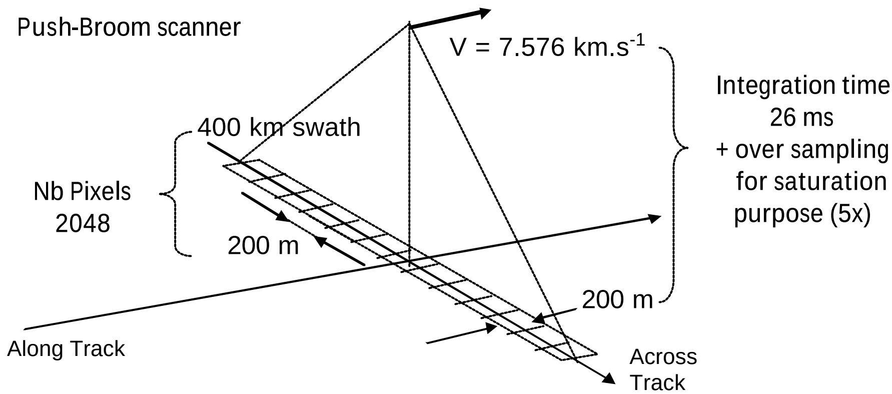
5. Mission Concept

5.5 Orbit Injection



6. Payload Definition

Spatial resolution requirements fulfillment



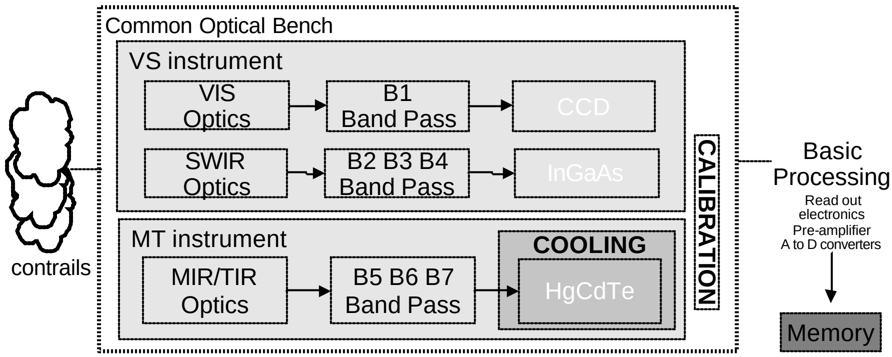
6. Payload Definition

Wavelengths requirements

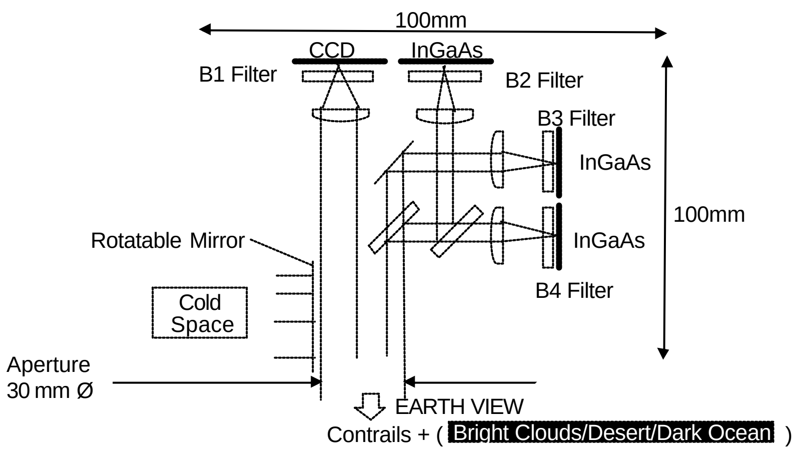
	VIS	SWIR			MIR	TIR	
Bandnumber	B1	B2	B3	B4	B5	B6	B7
Wavelength (µm)	0.66	1.24	1.38	1.66	3.90	10.80	12.00
Bandwidth (FWHM) (µm)	0.02				1.0		
Radiometric Requirements	> 7 bit						

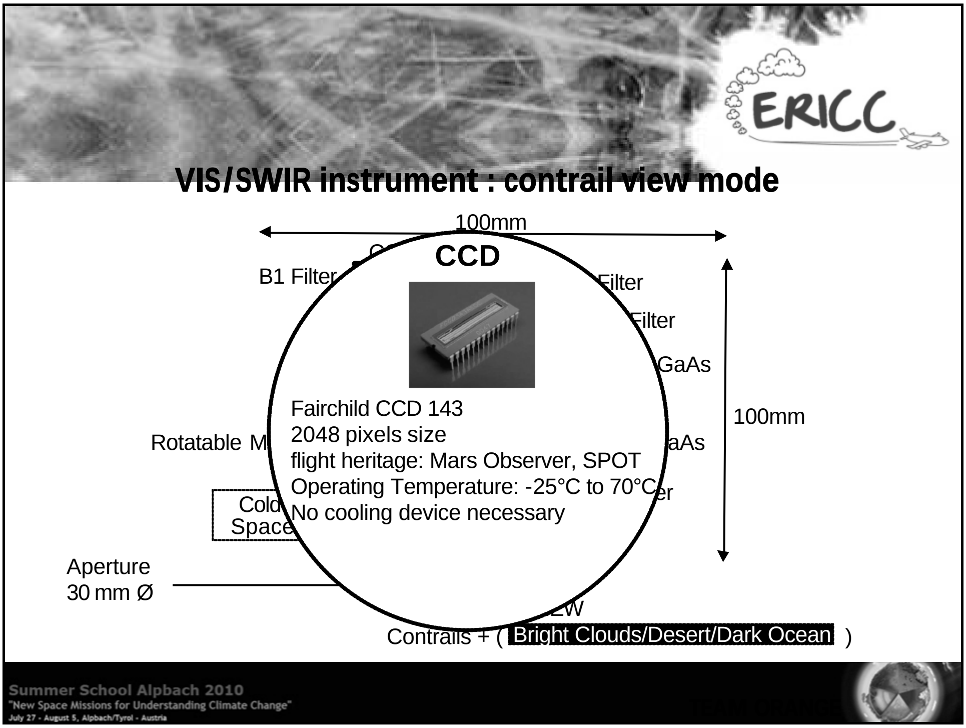
6. Payload Definition

Payload and instruments general design



VIS/SWIR instrument : contrail view mode

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VIS/SWIR instrument : contrail view mode
100mm
B1 Filter
Filter
Filter
GaAs
100mm
Rotatable M
aAs
Cold
Space
er
Aperture
30 mm Ø
CCD
Fairchild CCD 143
2048 pixels size
flight heritage: Mars Observer, SPOT
Operating Temperature: -25°C to 70°C
No cooling device necessary
Contrails + (Bright Clouds/Desert/Dark Ocean)
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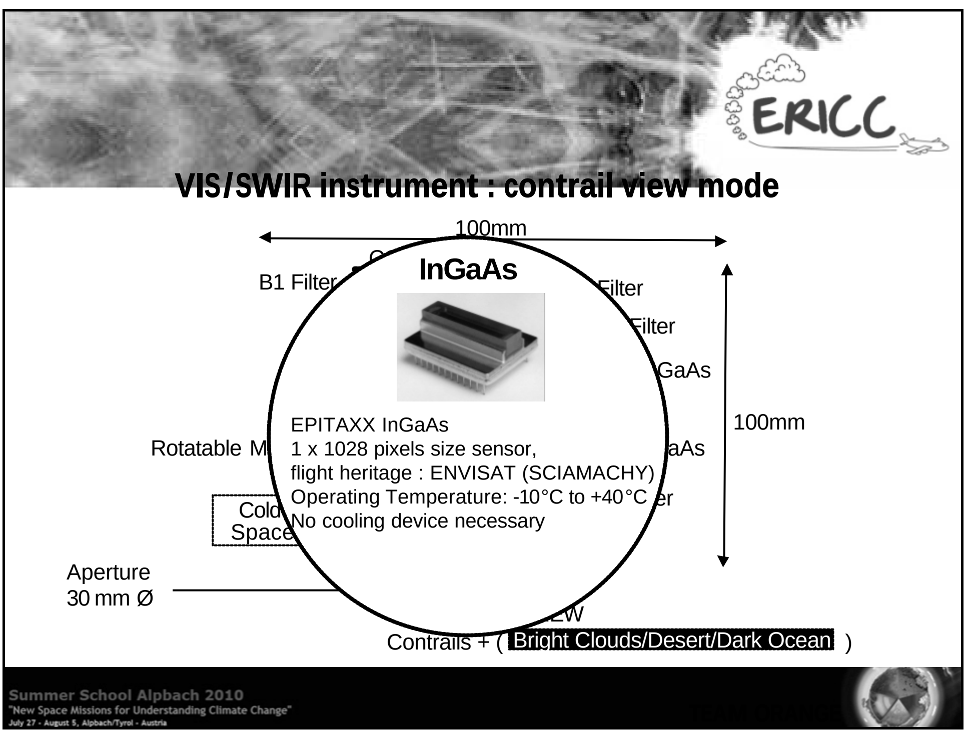
ERICC
VIS/SWIR instrument : contrail view mode
100mm
B1 Filter
Filter
Filter
GaAs
100mm
Rotatable M
aAs
Cold
Space
er
Aperture
30 mm Ø
InGaAs
EPITAXX InGaAs
1 x 1028 pixels size sensor,
flight heritage : ENVISAT (SCIAMACHY)
Operating Temperature: -10°C to +40°C
No cooling device necessary
Contrails + (Bright Clouds/Desert/Dark Ocean)
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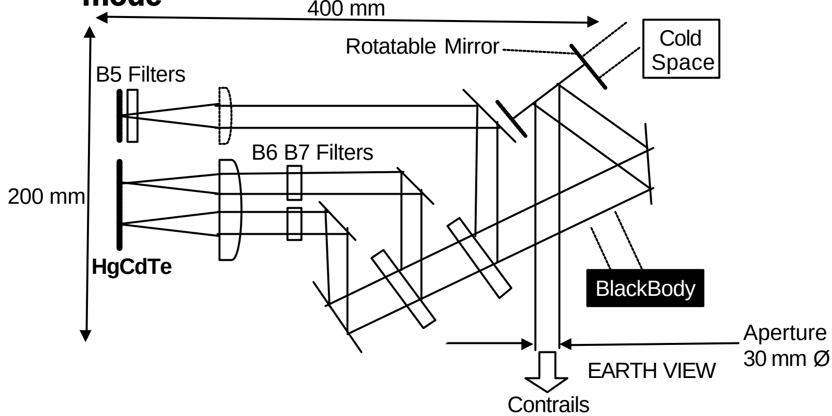
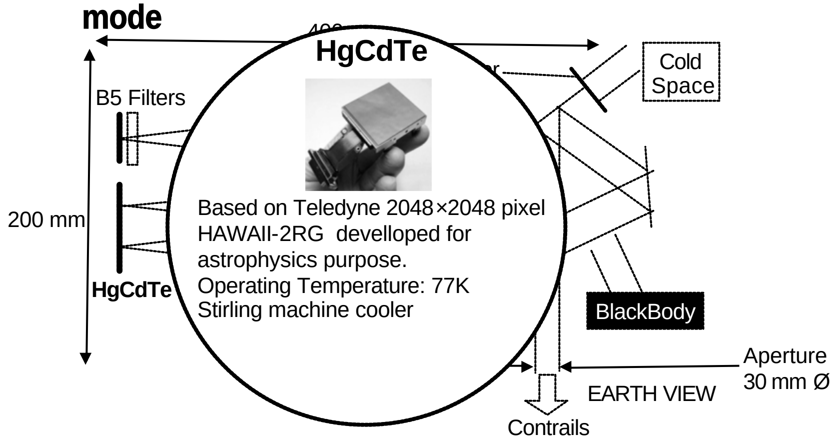
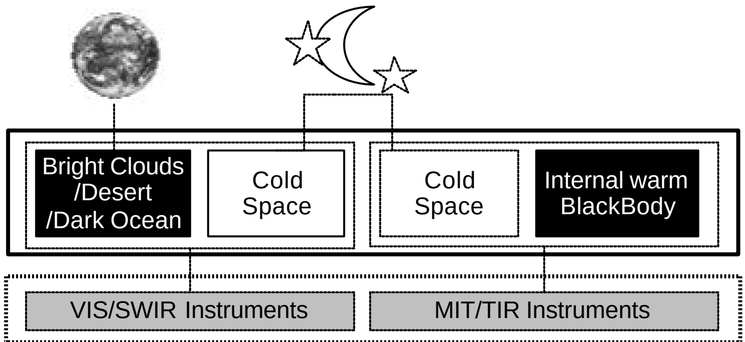
MIR/TIR instrument : contrail view mode



MIR/TIR instrument : contrail view mode



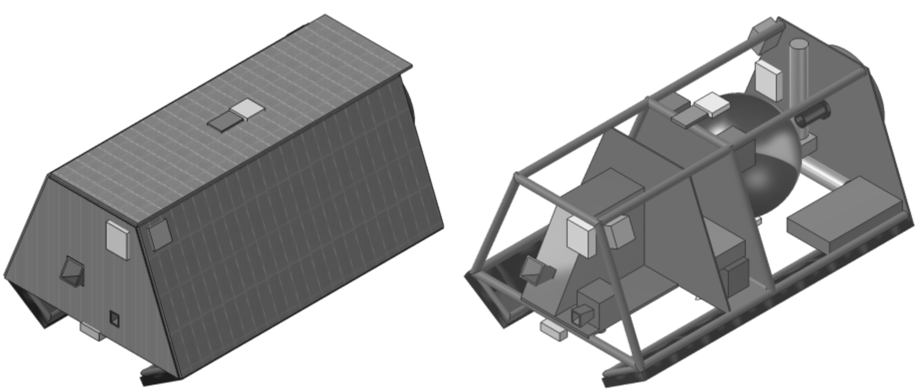
How to fulfill the accuracy requirements : Calibration



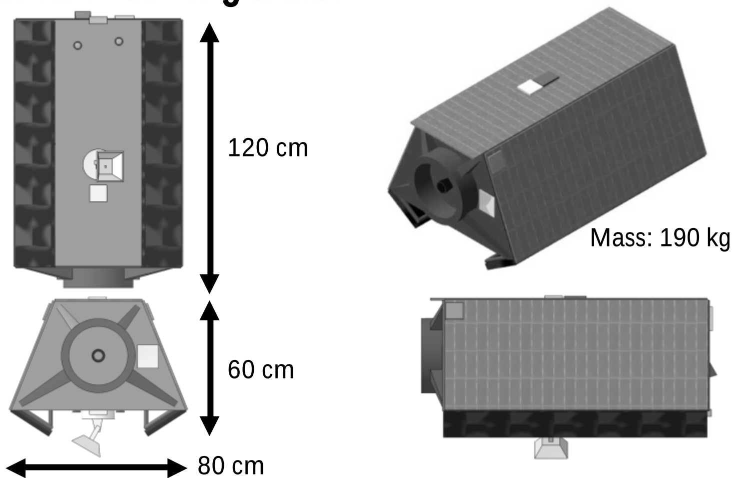
Bright/Warm Source = high emissivity (ie low reflectivity)

Cold Source = low emissivity (ie high reflectivity)

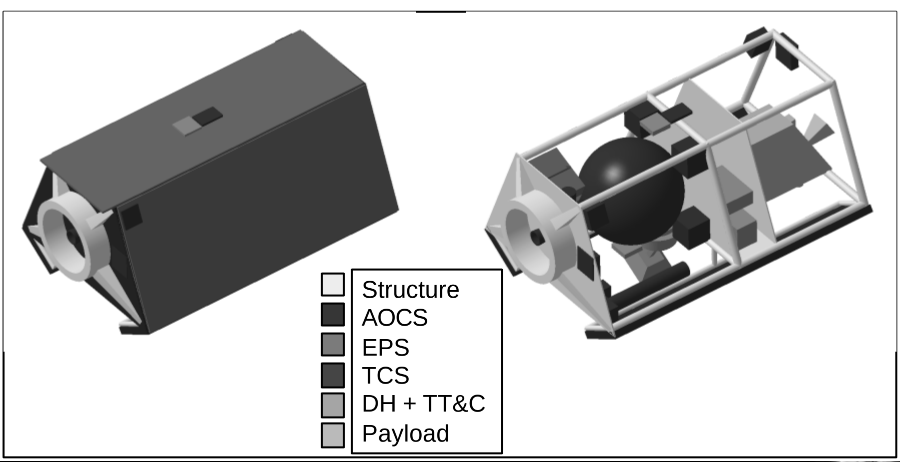
7. Spacecraft Design



7. Spacecraft Design



7. Spacecraft Design

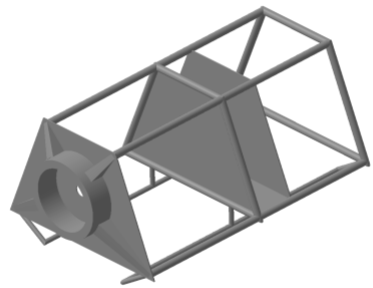


7. Spacecraft Design

7.1 Structure & Radiation Protection

Structure

- Strong baseplate
- Fairing interface to launcher
- Light beam structure



Radiation Protection

- Electronics Box protected by 2-3mm Aluminium Shielding

7. Spacecraft Design

7.2. Attitude and Orbit Control System (AOCS)

Mission Requirements

- **Pointing directions: Nadir pointing – instruments**
- **Payload pointing accuracy: 0.02 deg**
- **Pointing stability: 0.2 deg/sec**
- **Accuracy of attitude knowledge: 10 arcsec**
- **Slew rate: max 90 deg/min**
- **Precise Orbit determination: 200 m**
- **Perform Delta V**

Orbit Transfer (800 to 566 km)	?125 m/s
Orbit maintenance	?19 m/s
End of mission deorbit	?46 m/s
Total Delta V	**?190 m/s**

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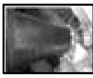
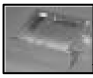
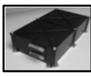
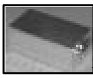

2x Star trackers (~10 arcsec)


2x Sun Sensors (~1 deg)


1x I.M.U. (~1 deg)


1x Magnetometer (sensitivity ~10 nT)

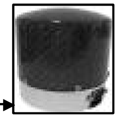

1x GPS (position ~10m, speed ~0.15m/s)

OBDH computer (AOCS)

3-axis stabilisation

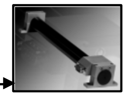
4x Reaction Wheels

Torque >100 mNm, Ang.mom: 1.5 Nms



3x Magnetorquers

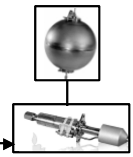
Magn. moment: 60 Am^2



Hydrazine propulsion

1x **Thruster** (~1N), tank, etc

Hydrazine (Isp ~220s)



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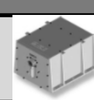
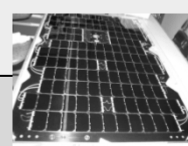
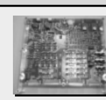
7. Spacecraft Design

7.3. EPS

Energy subsystems	Requirements	Solution
Battery Capacity	15 Ah	54 Ah lithium-ion (SAFT®) 
Power needed for entire orbit	270 W	GaAs/Ge Solar panels (Surrey®) 
Solar Panel surface needed	1.1 m² if constant incidence angle	2.25 m² set on 4 separate wall surfaces.
PCDU	28 Volt regulated bus	28 Volt power switches (Surrey®) 

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7. Spacecraft Design

7.4. Thermal Control System

Challenges

- Stabilize Sensors
- Only surface not pointing significantly towards sun is earth-facing side
- Complicated illumination conditions due to non SSO

Solution

- Cooler to stabilize MIR/TIR sensors
- Passive thermal control elements including body-mounted radiators, MLI, heat-pipes
- Radiators of $0.5m^2$ area at earth-facing side at 33° angle

7. Spacecraft Design

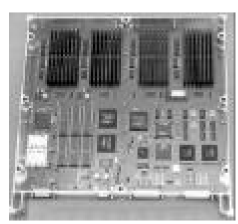
7.5. On Board Data Handling

Requirements

- Storage Capabilities: 150 Gbit (6 orbits of data)
- Fast memory access for storage of payload data

Solution

- Two redundant on board computers (master-slave configuration)
- Factor 2 data compression, 75 Gbit storage required
- One high speed data recorder unit, 128 Gbit storage



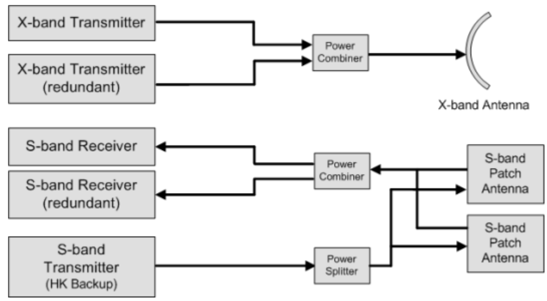
SSTL On board computer, TRL 9

7. Spacecraft Design

7.6. Telemetry Tracking and Control (TT&C)

Requirement
- 12,5 Gbit of data download per orbit

Solution
- Data rate: 140 Mbit/s
- Orbit data download time: 1,5min

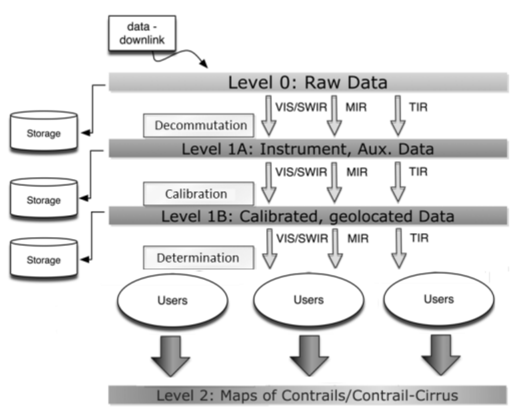


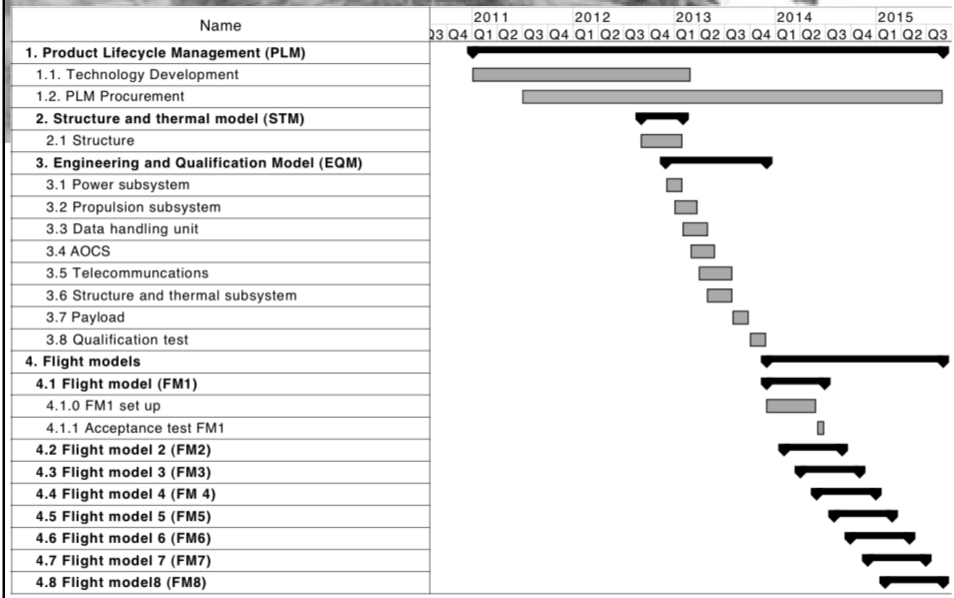
8. User Data Processing

Level 1A:
Instrument data, auxiliary data, ...

Level 1B:
Calibrated and geolocated data (Radiances in [W/m^{2}sr^{-1}])

Level 2:
Geophysical values of contrails/contrail-cirrus





9. Programmatics

9.2. Risk Assessment

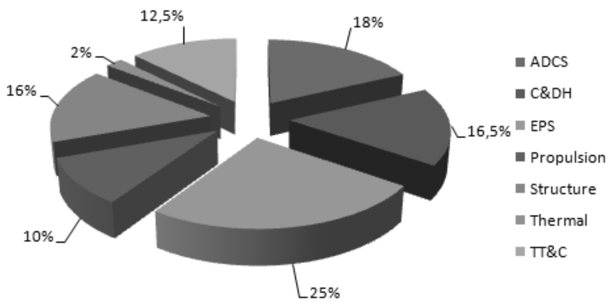
The risks of the mission are:

- Delivery delay of payload —> delay of production schedule.
- Technology used of TRL 8 or above, only battery has a certain risk.
- Single failure tolerant spacecraft design

9. Programmatics

9.3. Costs

Spacecraft bus (no payload)

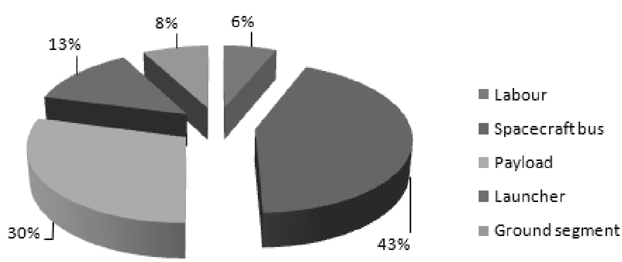


Spacecraft bus cost @ 8 models (average) = 10 million €

9. Programmatics

9.3. Costs

Total mission



Mission cost = 191 million €

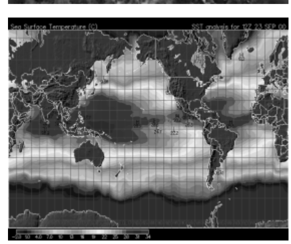
9. Programmatics

9.4. De-scoping Possibilities

Downgrade opt.	Effect	Scientific compromises	Impact on mission objective
Fewer satellites	Lower costs Either shorter period with 1 h time resolution or longer time between satellites	Less data on evolution of contrails and contrail cirrus	Medium to high
Fewer bands	Lower costs Less data Less mass Lower power consumption	Difficulties in retrieving data over different surfaces	Medium

10. Secondary Applications and Public Outreach

10.1. Secondary Applications



- **Sea surface temperature:**
  MIR and TIR bands
- **Land surface temperature:**
  TIR bands
- **Fire detection:**
  SWIR, MIR and TIR bands
  - Not for real time monitoring

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10. Secondary applications and Public Outreach

10.2. Public Outreach

- School educational programs for distribution
- Combination with online tools
- Connecting to science centers (ECSITE) and science shows (EPF) in Europe

11. Conclusion

"ERICC is a new space mission with great potential for the improved understanding of climate change"

- Novel science objectives
- Improved capabilities over previous missions
- Complementary to existing and future missions
- Innovative technical solutions to demanding science requirements
- Good technological grounding
- Economical proposal

Acknowledgements

Warm thanks to Helen and Klaus for their patience, support and expertise throughout the project.

Thanks to the various roving tutors who advised us and Suggested improvements to our mission.

We are indebted to our national science agencies for their generous funding.

Finally, we gratefully acknowledge the Summer School Organizers and staff for this unique opportunity.

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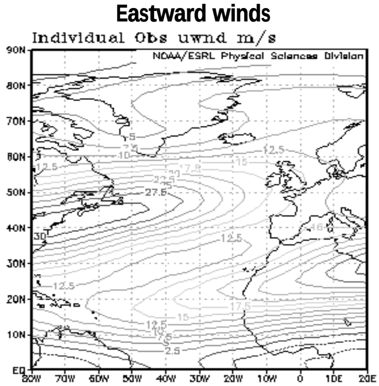
EXTRA SLIDES

Jet streams

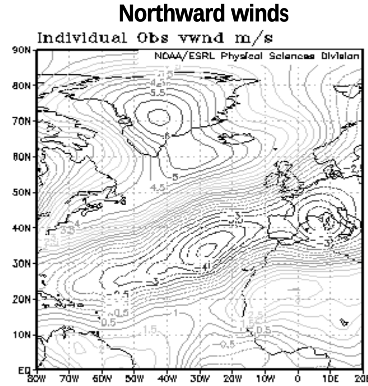
Wind speeds:

40-50 degrees N: ~ 30.0 m/s east, 50-60 degrees N: ~ 13.5 m/s east-north-east

Eastward winds



Northward winds



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Jet streams

Possibility for geostationary satellites:

MTG / FCI in rapid scan mode:	
Region	Europe and northern Africa
Spatial resolution	500 m
Revisit time	2.5 min
Total number of channels	16
Channel 1 (0.66)	Yes
Channel 2 (1.24)	No
Channel 3 (1.38)	Yes
Channel 4 (1.66)	Yes
Channel 5 (3.90)	Yes
Channel 6 (10.80)	Yes
Channel 7 (12.00)	Yes

Mass budget

Payload	Mass (kg)	Margin 20%	TRL
Spectral Imager	40	48	6
Bus			8
Structure	48.8	58.6	9
AOCS	41.3	5	9
EPS	22.2	26.6	9
Thermals	7.6	9.12	8 to 9
TT&C	6.5	7.8	9
Onboard computer	2.7	3.24	9
Total bus	129.1	110	
Total system	169.1	158	
System margin		31.6	
Total with margin (20%)		190	

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Telemetry Tracking and Control (TT&C)

Requirement:

- 12,5 Gbit of data download per orbit

Solutions:

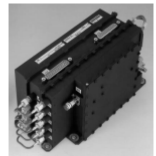
X-band Telemetry Downlink

- Data rate: 140 Mbit/s
- High gain antenna (horn antenna, tracking)
- Transmit power: 3.5 W

S-band Telecommand Uplink

- Data rate: 0,5 Mbit/s

S-band Backup Telemetry Downlink (HK data only)



X-band transmitter (Alcatel)

X-band horn antenna (SSTL)

TT&C Link Budgets

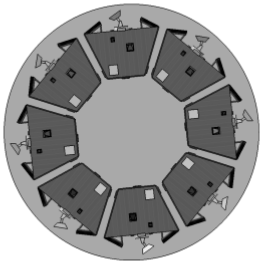
Spacecraft -> Earth downlink

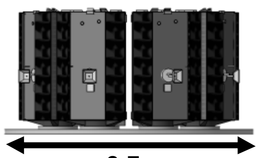
X-band Downlink		
User Data Rate	140	Mbit/s
Modulation Grade (M)	4	(QPSK)
Code Rate	0,5	
Symbol Rate	1	
Roll-off Factor	0,5	
Bandwidth	210	MHz
Bandwidth [dBHz]	83,22219295	dBHz
Frequency	8,2	GHz
TX Output RF Power	**3,55**	**W**
Transmitter Efficiency		
TX Input Power	**35**	**W**
TX Antenna Gain	12,85	dBi
TX Loss	3	dB
EIRP	**15,35228353**	**dBW**
Satellite Orbit Altitude	566	km
Minimum Elevation	5	deg
Maximum Distance to Satellite	2112	km
Free Space Loss	177,2119275	dB
Atmospheric Loss	1	dB
Pointing Loss	2	dB
Demodulator Loss	2	dB
Combiner Loss	3	dB
Boltzmann Constant	228,60	dBJ/K
Ground Station:		
RX Antenna Size	15	m
G/T	37,5	dB/K
C/N0	**96,24**	**dBHz**
Eb/N0	**13,02**	**dB**
Required Eb/N0	10	dB
Margin	**3,02**	**dB**

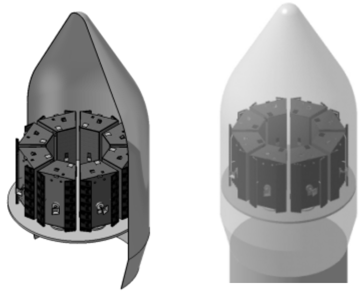
Earth -> Spacecraft uplink

S-band Uplink		
User Data Rate	0,5	kbit/s
Modulation Grade (M)	4	(QPSK)
Code Rate	0,5	
Symbol Rate	1	
Roll-off Factor	0,5	
Bandwidth	0,75	MHz
Bandwidth [dBHz]	58,75061263	dBHz
Frequency	2,1	GHz
TX Antenna Size	15	m
EIRP	**45**	**dBW**
Satellite Orbit Altitude	566	km
Minimum Elevation	5	deg
Maximum Distance to Satellite	2112	km
Free Space Loss	165,3800364	dB
Boltzmann Constant	228,60	dBJ/K
Ground Station:		
RX Antenna Gain	3	dB
Pointing Loss	6	dB
Feed Loss	2	dB
Combining Loss	3	dB
Atmospheric Loss	1	dB
Tant	290	K
LNA Noise Figure	0,8	dB
Tsys	348,656686	K
Tsys [dBK]	25,42397998	dBK
G/T	-22,42397998	dB/K
C/N0	**73,80**	**dBHz**
Eb/N0	**15,05**	**dB**
Required Eb/N0	10	dB
Margin	**5,05**	**dB**

Launcher Configuration (PSLV)







Mass

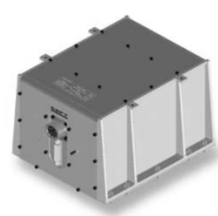
- Single Satellite: 190 kg
- Total Satellite: 1520 kg
- Fairing mass: 350 kg
- **Total mass: 1870 kg**

EPS System solution (1)

- **Battery**

Number of cycles : 12500
Capacity needed : 15 Ah
Power needed during eclipse : 122W

Chosen battery :
54.4 Ah 28V SAFT lithium-ion battery



- **Power and Control Distribution Unit (PCDU)**

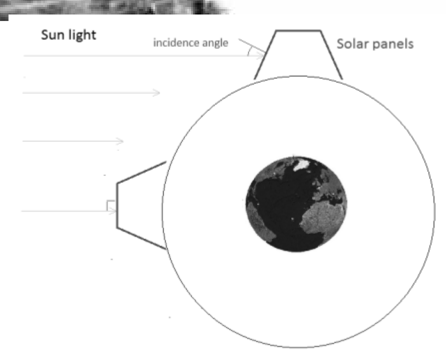
Surrey Small Satellite Power System (flight heritage : (DMC, CFESAT, RapidEye)
28 x 28 volt power switches
Compatible with 28V Li-Ion batteries

7. Spacecraft Design

7.3. EPS

Features	Requirements
Required eclipse mean power	122 W
Required daytime mean power	133 W
Load voltage	28 V
Life time	5 years

EPS system solution (2)



- **Solar Panels concept**

Solar panels are directly set on the walls :
High incidence angle variation, SP must be oversized (Integration over one daytime period have been computed).

- **Technology used**

-SURREY gallium arsenide on
- germanium (GaAs/Ge) solar cells
(28% efficiency, low degradation rate, ALSAT heritage)
- solar panels surface : 2.25 m^2

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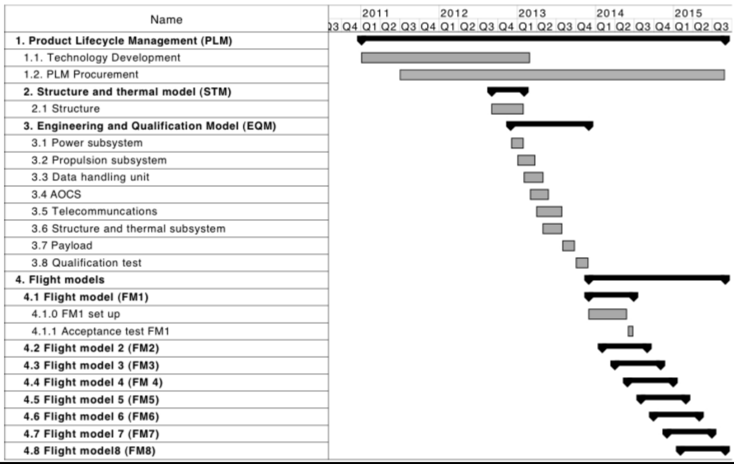
Project Timescale



X. Mission costs (backup)

1st approach

Mission costs breakdown (million €)	
Spacecraft cost	10
Payload	7
Satellite cost	17
Labour cost	12
STM	3
EQM	12
Building cost (constellation)	151
Launcher	25
Ground segment	15
Total misión cost	191

X. Mission costs (backup)

2nd approach

Mission costs breakdown (million €)	
Spacecraft cost	18
Payload	12,6
Satellite cost	30,6
STM	20
EQM	30,6
FM1	18,36
FM2	15,3
FM3 to FM8	12,24
Launcher	25
Ground segment	15
Total misión cost	197,7

EPS Requirements vs Performance

Energy subsystems	Requirements	Solution
Mean power during eclipse	122 W	Direct Energy Transfer
Mean power during daytime	133 W	
Battery Capacity	15 Ah	54 Ah
Power needed for entire orbit	270 W	GaAs/Ge Solar panels
Degradation rate	2.75 %/year max	No degradation noted in 20000 cycles (mission heritage)
Solar Panel surface needed	1.1 m² if constant incidence angle	2.25 m² on separate wall surfaces
PCDU	28 Volt loads	28 x 28 Volt power switches

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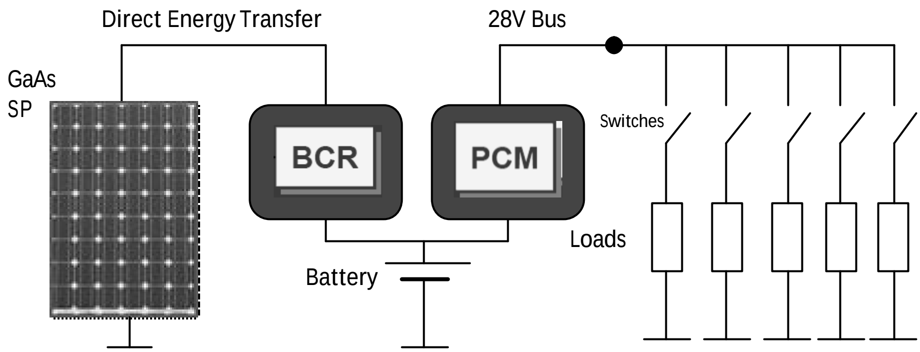
7. Spacecraft Design

7.3. EPS

Overview



Difference from other missions

- Can add to existing programs of ESA (GMES and Living Planet)
- Compared with: AQUA, TERRA/MODIS, MSG/SEVIRI, MTG/FCI, SENTINEL-2/MSI, SENTINEL-3/SLSTR, LANDSAT 7/ETM, ENVISAT/MERIS, NOAA/AVHRR 3, NOAA/HIRS 4

	Polar satellites	Geostationary satellites	ERICC
Number of satellites	1-4	4	8
Revisit time	1-35 days	15 min	1 h – 1 day
SWATH	10-2000 km	Earth disc	410 km
Spatial resolution	30 m – 260 km	1 – 3 km	200 m
Number of the 7 channels	1-5	3-6	7

Comparison to other missions – backup 1

	AQUA, TERRA/ MODIS	MSG/SEVIRI	MTG / FCI	SENTINEL-2/ MSI	SENTINEL-3/ SLSTR
Number of satellites	2	4	4	2	2
SWATH	2330x10 km	Earth disc, Europe	Earth disc, Europe	290 km	750 km
Spatial resolution	250-1000 m	1-3 km	500-2000 m	10-60 m	500-1000 m
Revisit time	2 days	15 min	2.5-10 min	1-2 days	1-2 days
Total # channels	7	12	16	13	9
Channel 1 (0.66)	Yes	No	Yes	Yes	Yes
Channel 2 (1.24)	Yes	No	No	no	No
Channel 3 (1.38)	Yes	No	Yes	Yes	Yes
Channel 4 (1.66)	No	No	Yes	Yes	Yes
Channel 5 (3.90)	No	Yes	Yes	no	No
Channel 6 (10.80)	Yes	Yes	Yes	no	Yes
Channel 7 (12.00)	Yes	Yes	Yes	no	Yes

Comparison to other missions – backup 2

	LANDSAT 7/ ETM	ENVISAT / MERIS	NOAA / AVHRR 3	NOAA / HIRS 4
Number of satellites	1	1	4	2
SWATH	183 km	1150 km	10 km	10 km
Spatial resolution	30-60 m	260 km	1 km	500 m
Revisit time	16 days	35 days	1 day	1 day
Total # channels	8	16	6	17
Channel 1 (0.66)	Yes	Yes	Yes	No
Channel 2 (1.24)	No	No	No	No
Channel 3 (1.38)	No	No	No	No
Channel 4 (1.66)	Yes	No	No	No
Channel 5 (3.90)	No	No	Yes	Yes
Channel 6 (10.80)	No	No	Yes	No
Channel 7 (12.00)	No	No	Yes	No

X. Appendix

X.X Thermal Control System Backup 1/2

Ricor K508

• Integral Sterling Micro Cooler
• Cooling Power at 0°C ambient: 750 mW
• Mass: 450 g
• Ambient Temp. Range: operational: -40°C ... +85°C
• TRL9

X. Appendix

X.X Thermal Control System Backup 2/2

Assumption for Preliminary Thermal Analysis

- Margin in Power Input
- 5°C thermal margin for temperature limits
- Max./Min. Earth IR emission, Max. Solar Flux, Max. Albedo
- End of life white paint Emissivity and Absorptivity
- Radiator Area based on worst-case hot
- Radiator Temperature worst-case cold: -83°C
- Power needed to heat to 5°C: 135W

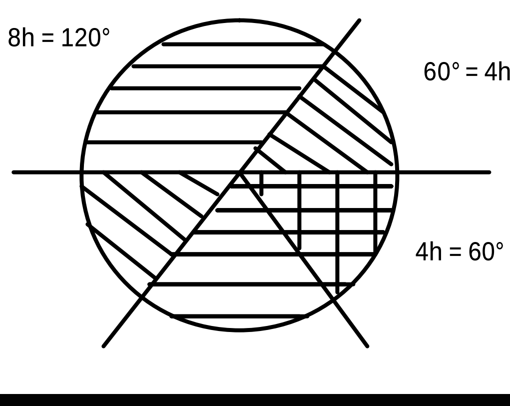
X. Appendix

X.X Mission Concept Backup 1

- Satellite velocity: v = 7.58 km/s
- Time of eclipse: t_E = 35.6 min
- Angular distance of true anomalie between two satellites of the constellation projected on the adjacent orbit: ?? = 216.6°

X. Appendix

X.X Mission Concept Backup 2



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