Green Team Presentation,

Alpbach Summer School

Aug. 5th, 2010

Presented by:

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CO_2 is responsible for 63% of the radiative forcing of all of the Green house gases. [IPCC Fourth Assessment Report [AR4] 2007]

Global emissions from biomass burning produce 40% of the gross CO2 emissions annually. [Environmental Science & Technology Journal, NASA, 1995, Dr. J. S. Levine]

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Scientific Objective

- To observe biomass burning in the tropics and derive data on CO_2 emissions through measurements of fire radiative power.

Motivation

- Understanding how global climate change will affect the Earth system is the primary environmental science challenge of the early 21st century [ESA09]

- CO_2, a major green house gas is the major contributor to climate changes.
- Better quantification of the global carbon cycle is fundamental to understanding many of the dramatic changes taking place on Earth.

Motivation

- 40% of anthropogenic CO_2 release due to biomass burning
- 50% of uncertainty
- Ecosystem models can benefit from EO data

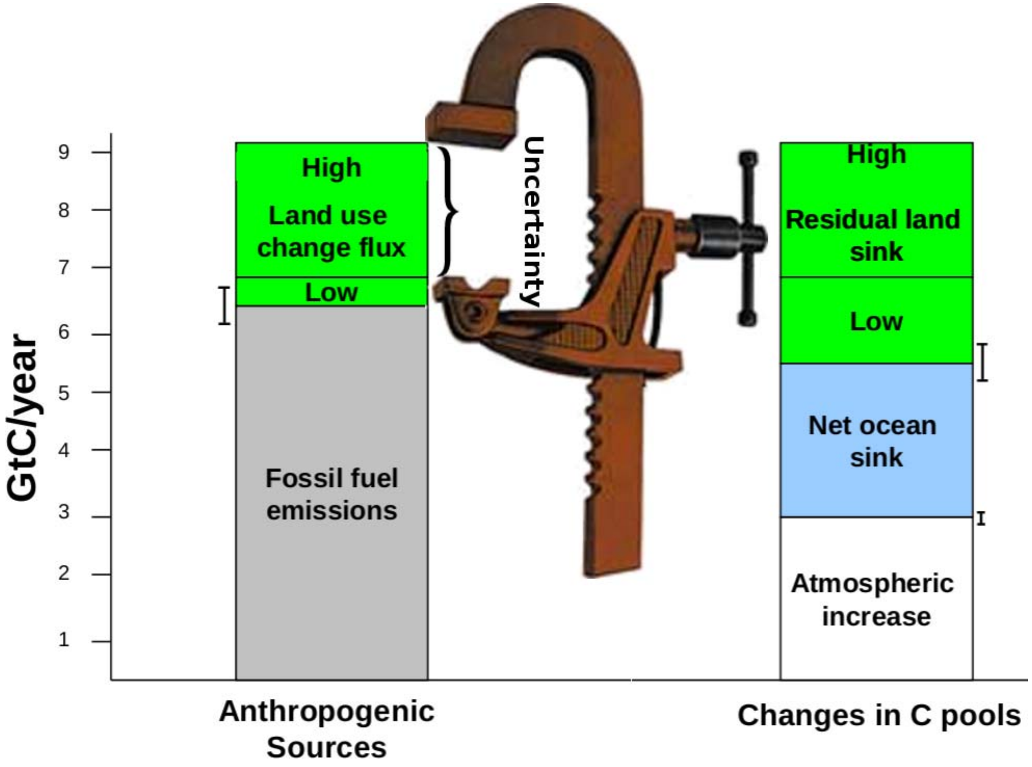
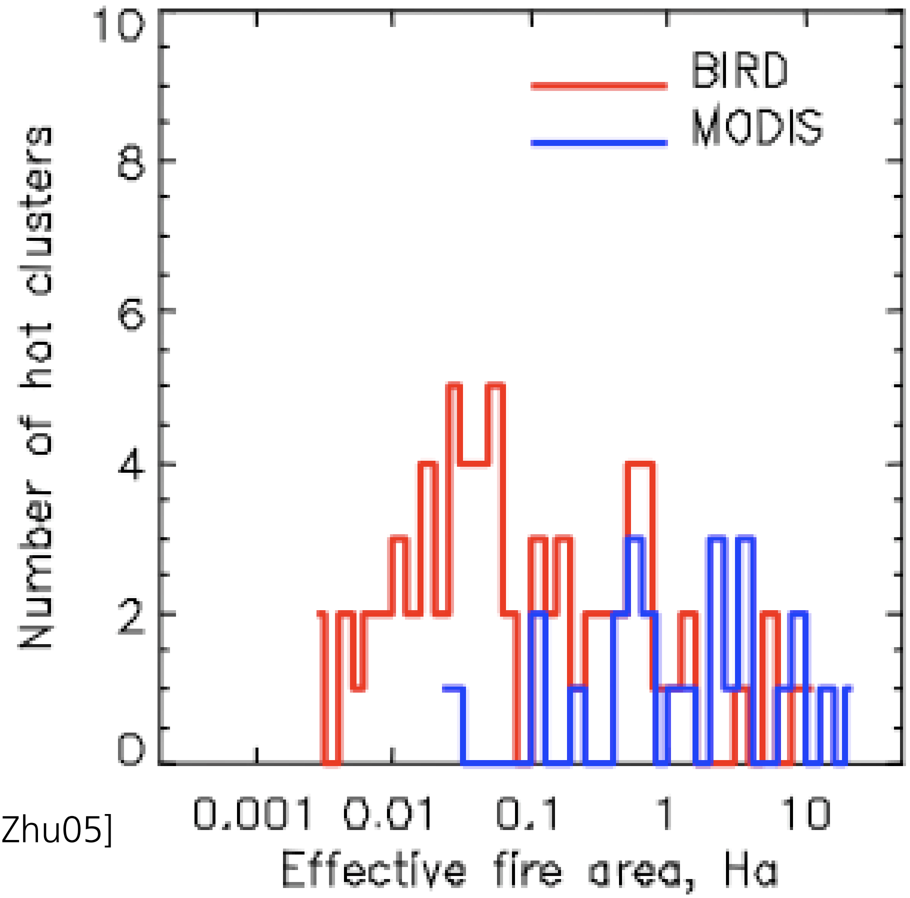


Image courtesy of Prof. S. Quegan (modified)

Scientific Requirements – Spatial Resolution

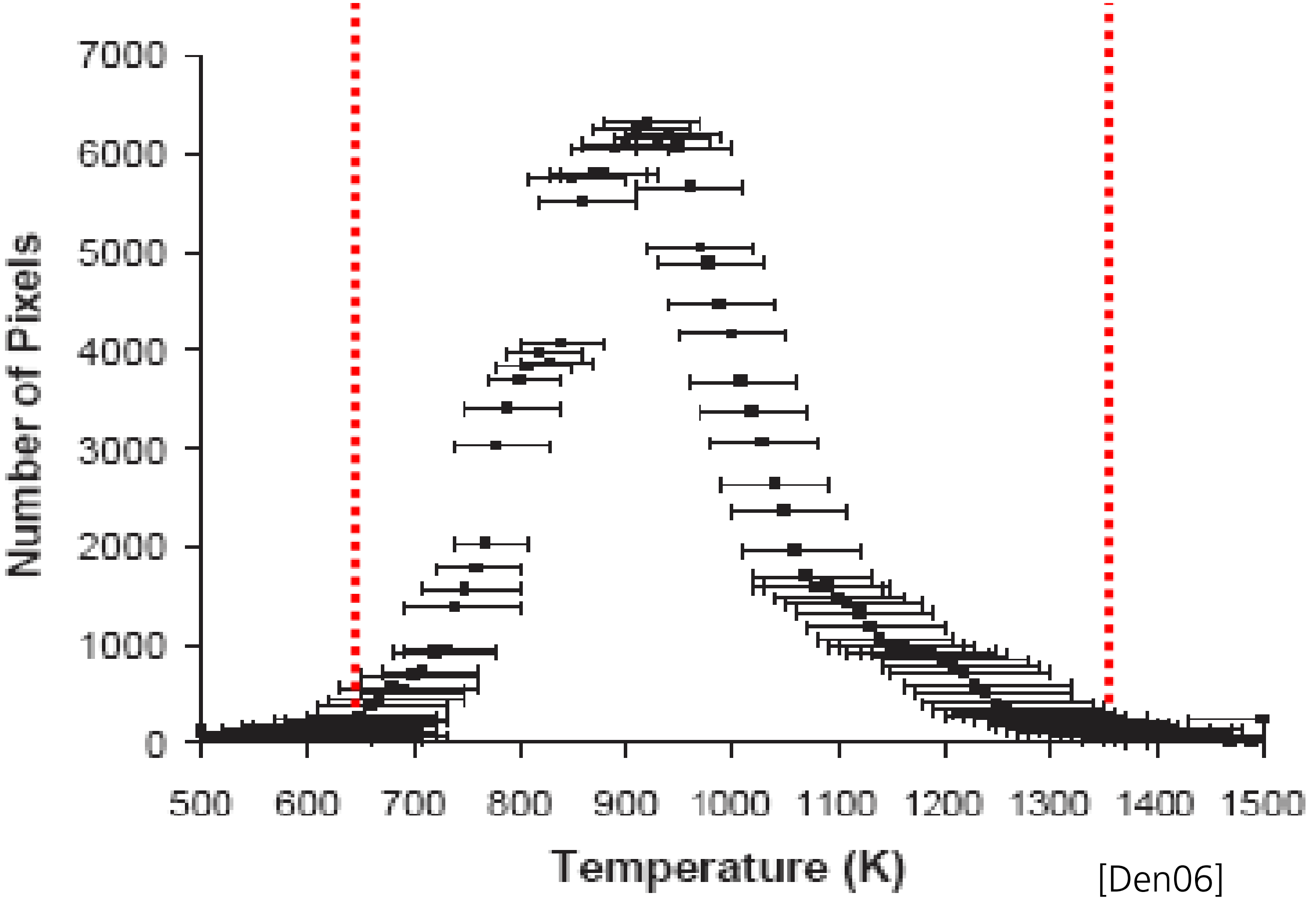
- Smallest effective fire area 500m²



[Zhu05]

Scientific Requirements – Fire Temperature

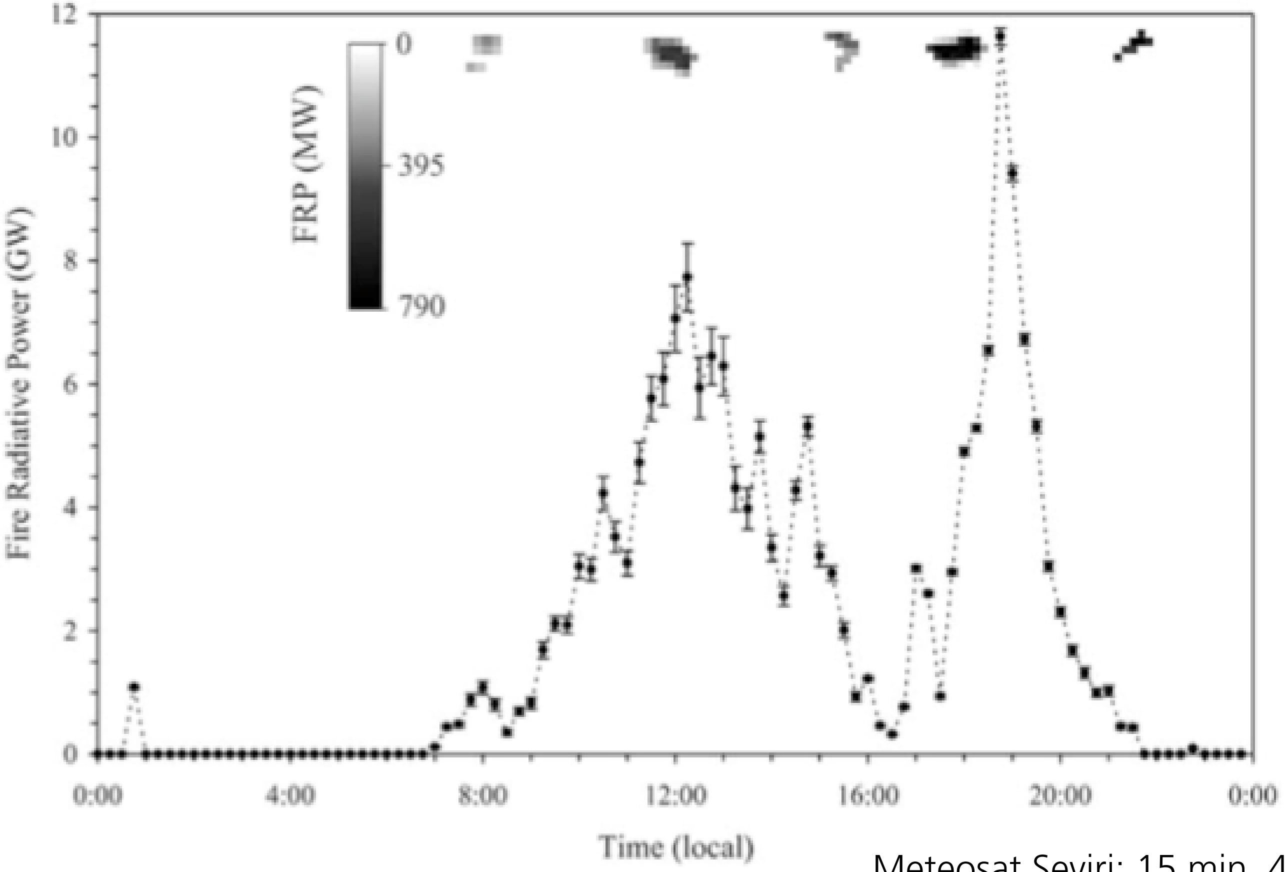
- 650 -1350 K



[Den06]

Scientific Requirements - Temporal Resolution

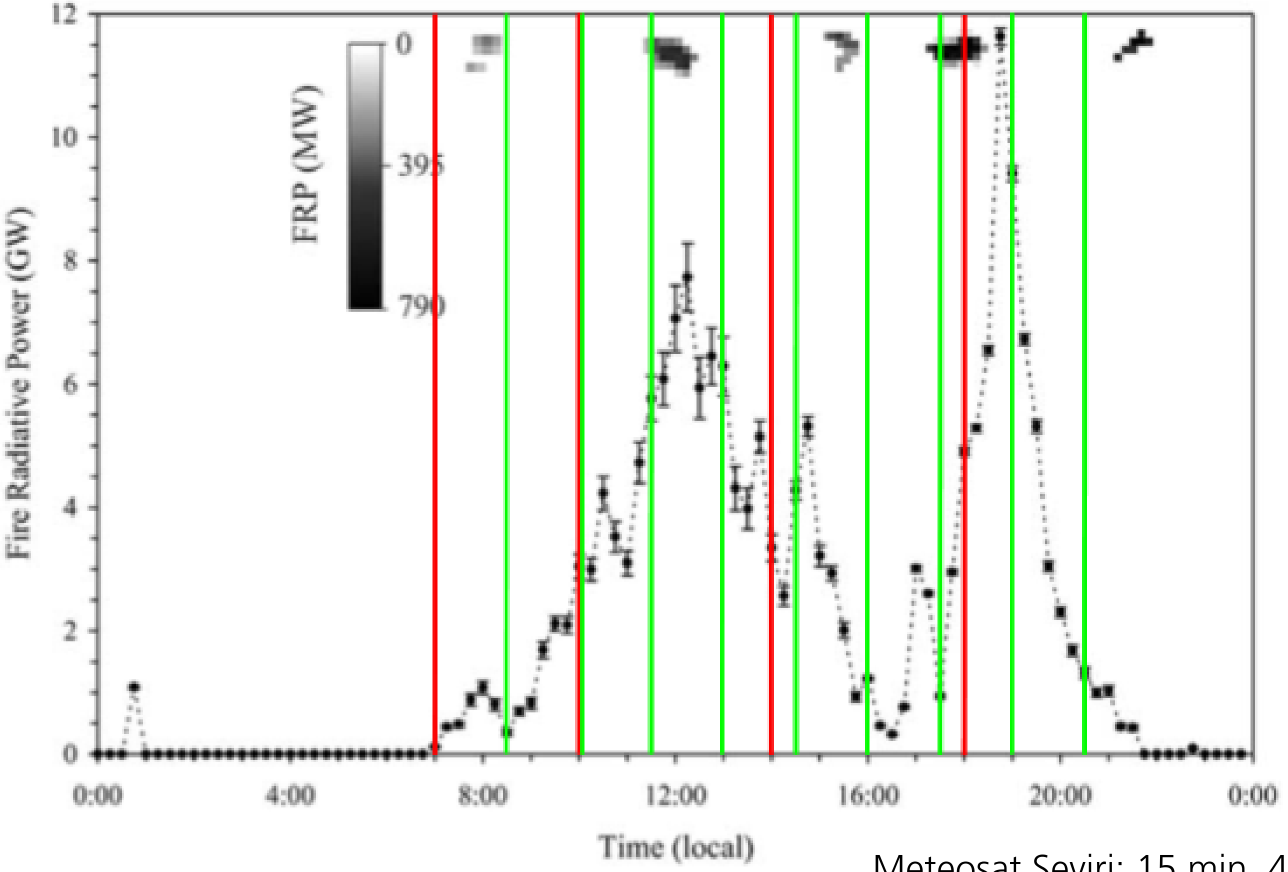
- Majority of emissions (>99%) within ~4-8 h [And01]



Meteosat Seviri: 15 min, 4.8 km [Woo05]

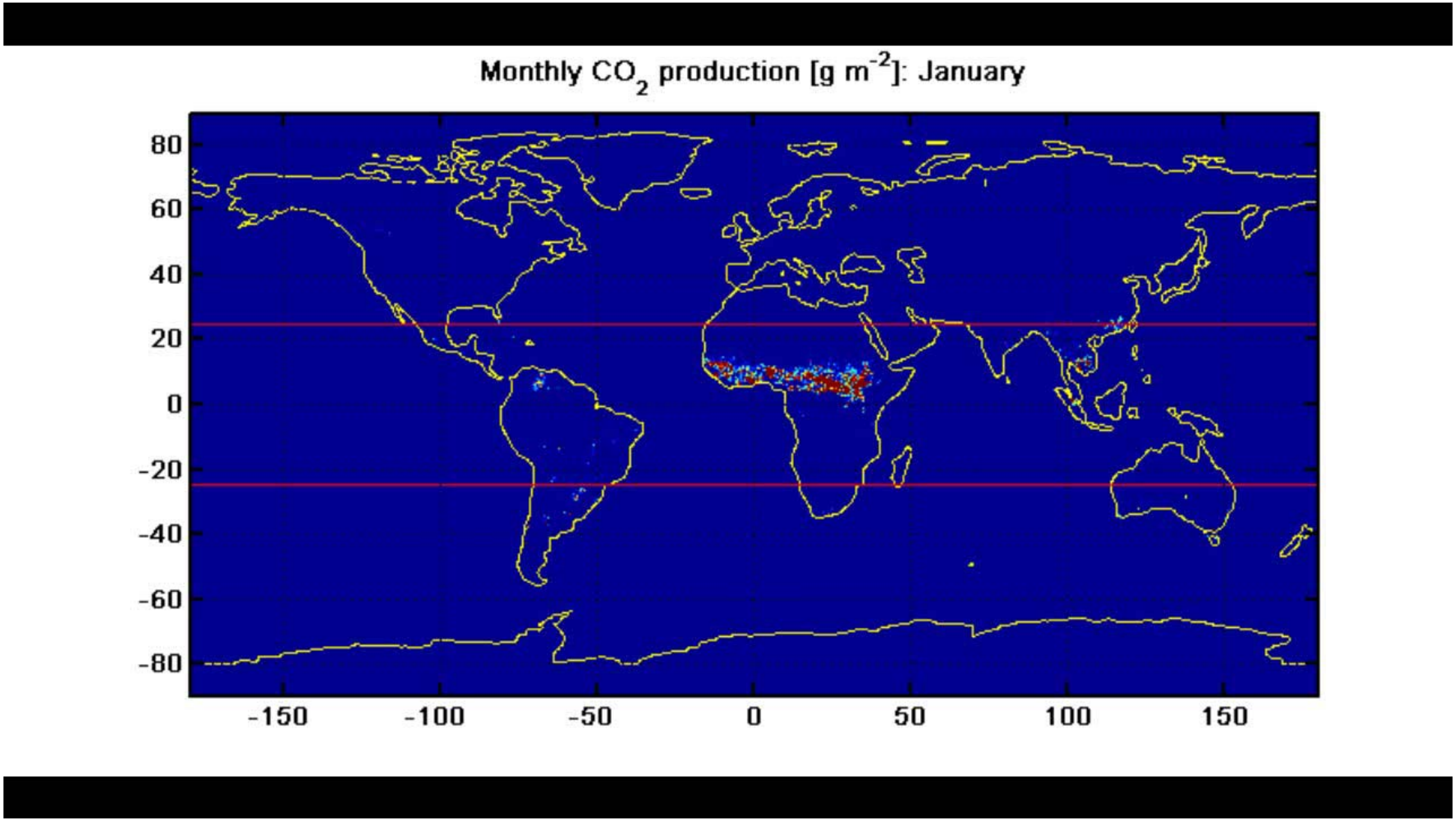
Scientific Requirements - Temporal Resolution

- Temporal Resolution:1.5 h, min. 4 h



Meteosat Seviri: 15 min, 4.8 km [Woo05]

Scientific Requirements – Latitude Range

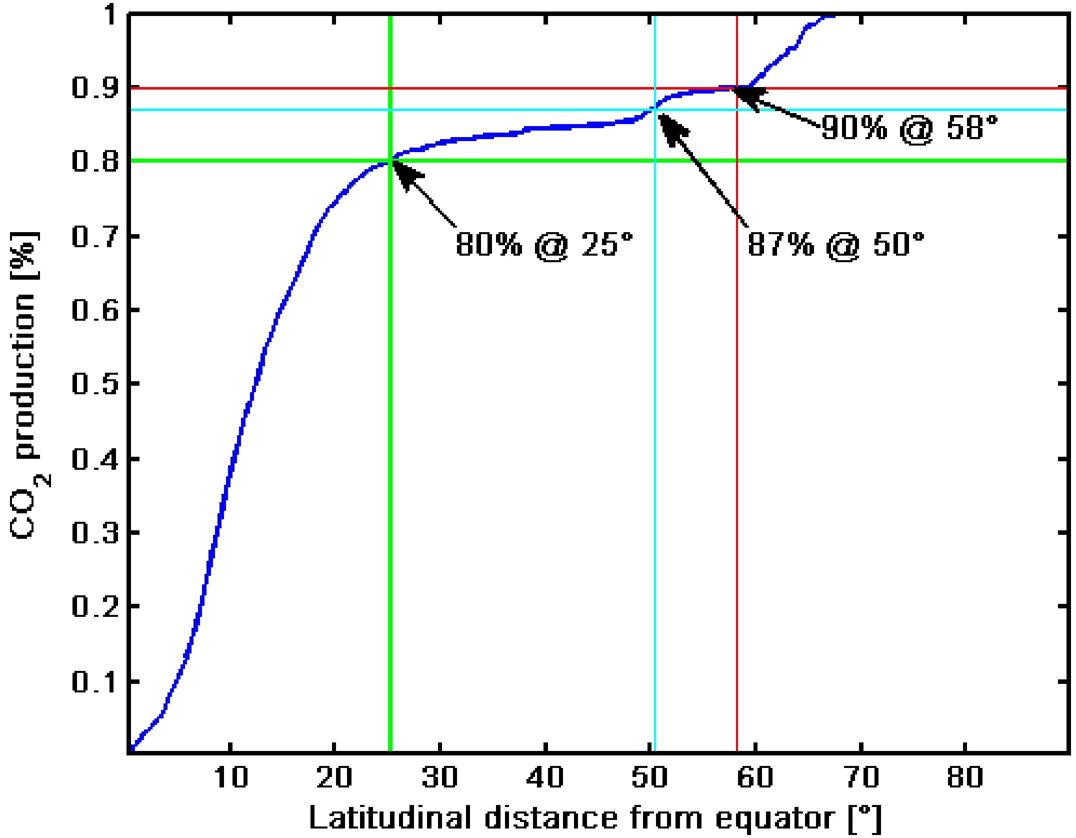


Animation: Green Team. Data: G.R. van der Werf, Global Fire Emissions Database

Scientific Requirements – Latitude Range

- Focus on 80% CO_2 release
- Lat: +/- 25°

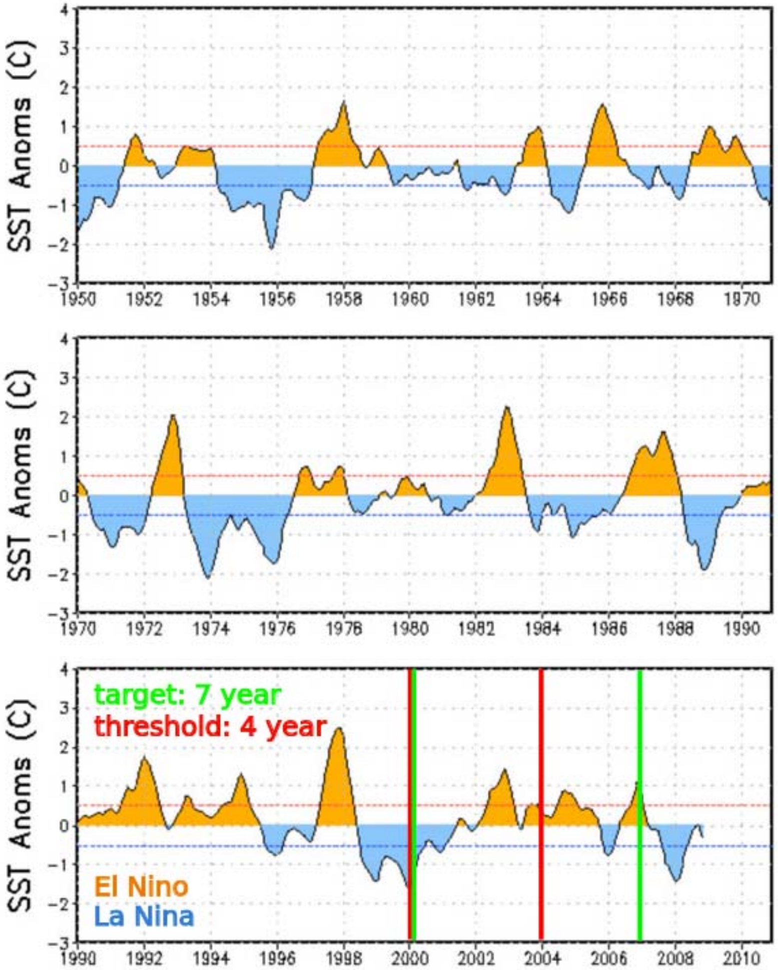
Cumulative annual CO_2 production



Animation: Green Team. Data: G.R. van der Werf, Global Fire Emissions Database

Scientific Requirements – Mission Duration

- El Nino Southern Oscillation has large influence on fires, droughts, …
- Cover one full ENSO cycle
- 7 years mission duration, 4 years minimum



[NOAA]

Summary of Scientific Requirements

	Target	Minimum	
Geolocation accuracy	500 m	1000 m	GEO calibration
Eff. area	500 m²	1000 m²	BIRD fire data
Spatial resolution	120 m	300 m	BIRD (minimum)
Temporal resolution	1 h	4 h	Dynamic of fire
Temperature min.	280 K	280 K	Background
Fire temperature max.	1400 K	1200 K	Dynamic range
Pixel brightness T res.	0.1 K	1 K	Sub-pixel detection
FRP min.	0.2 MW	1 MW	Sub-pixel detection
FRP max.	20 GW	10 GW	Sub-pixel detection
Mission duration	7 years	5 years	Cover ENSO
Data provision	daily	monthly	

Current and Future FRP Satellite Missions

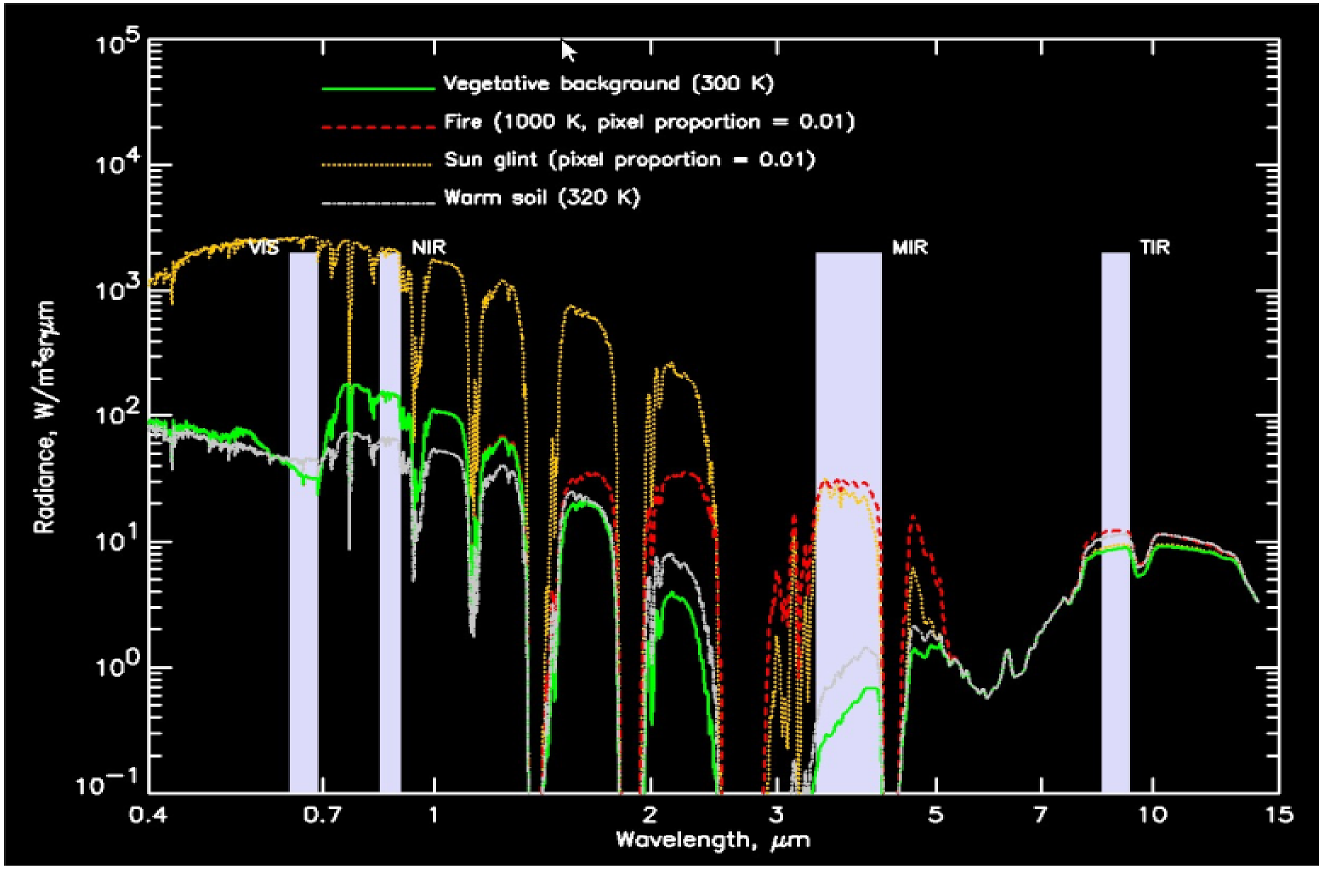
Mission	Sensors	Coverage		Resolution	
		Spatial	Temporal	Spatial	Temp.
GOES	GOES-E/W	N/S America	1995-present	4 km	30 min
TERRA	MODIS	Global	2001-present	1 km	1 day
METEOSAT	SEVIRI	Africa, Europe	2006-present	4.5 km	15 min
Sentinel 3	SLSTR	Global	2012-2035	1 km	daily
Bird	HSHR	Global	2001-2006	370 m	samples
TRMM	VIRS	Tropics	1997-2011	2.5km	92.5 min
VESTA	**VIS,NIR MIR, TIR**	**Tropics**	**2020-2027**	**115 m 230 m**	**1.5-4 h**

Secondary Scientific Objectives

- Assessment of aerosol emissions through combination of fire radiative power measurements and determination of effective fire temperature.

- Coverage of the land use change through determination of the Normalized Differential Vegetation Index (NDVI).

Methodology – Spectral Channels



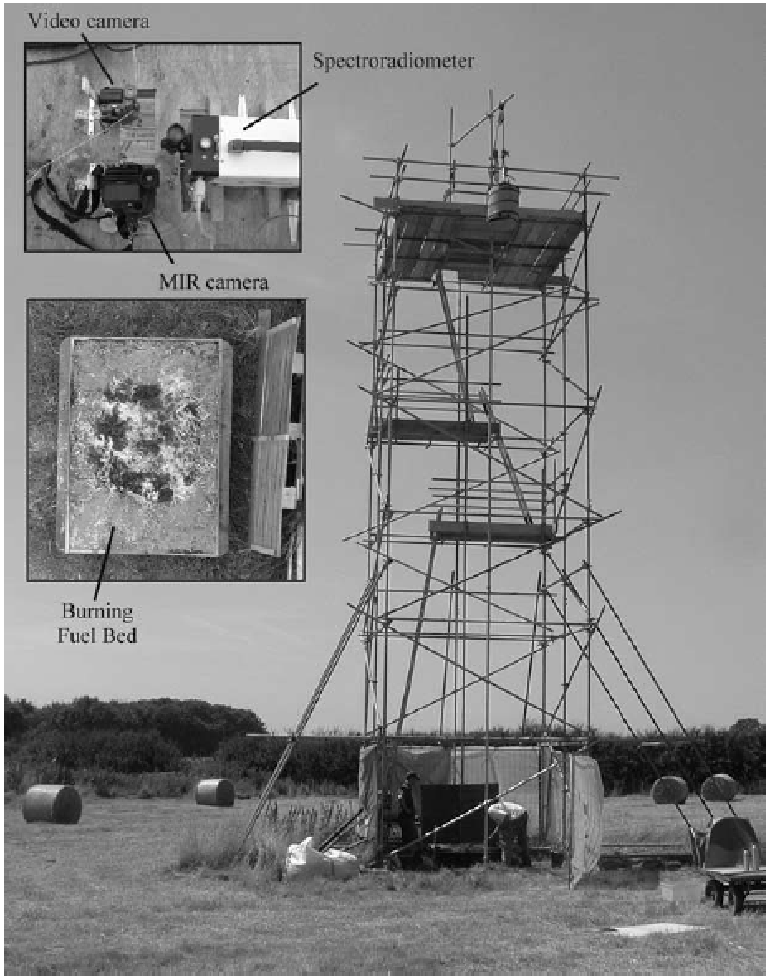
Atmospheric windows

VIS	0.4-0.7 µm
NIR	0.8-1.4 µm
MIR	3-4 µm
TIR	8-13 µm

[Courtesy of D. Oertel]

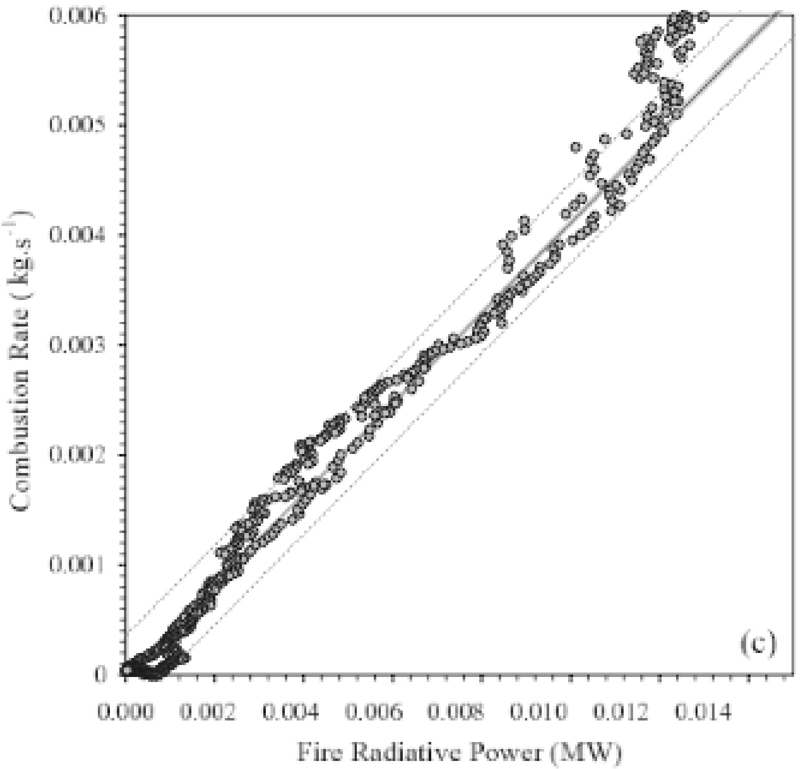
- MIR: Leading channel for fire detection
- VIS: Detect false alarms due to sun glints
- NIR: NDVI, Co-registration for sub-pixel
- MIR/TIR: Detect warm surface false alarms

Methodology – Fire Radiative Power



Scaffold tower with fuel bed, courtesy of M. Wooster

- Combustion rate of biomass proportional to FRP



Methodology – Derivation of FRP

- M.J. Wooster, 2005: Retrieval of biomass combustion rates and totals from observ. of fire radiative power
  - MIR radiance method (e.g. SEVIRI)

$$FRP_{MIR} = \left(\frac{\sigma.\varepsilon_f}{a.\varepsilon_{f,MIR}}\right) L_{f,MIR} \qquad [\mathrm{Wm}^{-2}]$$

- σ - Stefan Boltzmann constant
- ε_f is the emissivity of the fire over all wavelengths .
- $\varepsilon_{f,MIR}$ is the emissivity over the MIR spectral band.
- a: Experimental parameter
- Assumption: Grey bodies

  - „Modis method“

$$FRP_{MODIS} = 4.34.10^{-19}\left(T_{MIR}^{8} - T_{b,MIR}^{8}\right) \qquad [\mathrm{Wm}^{-2}]$$

Methodology – Fire Radiative Energy

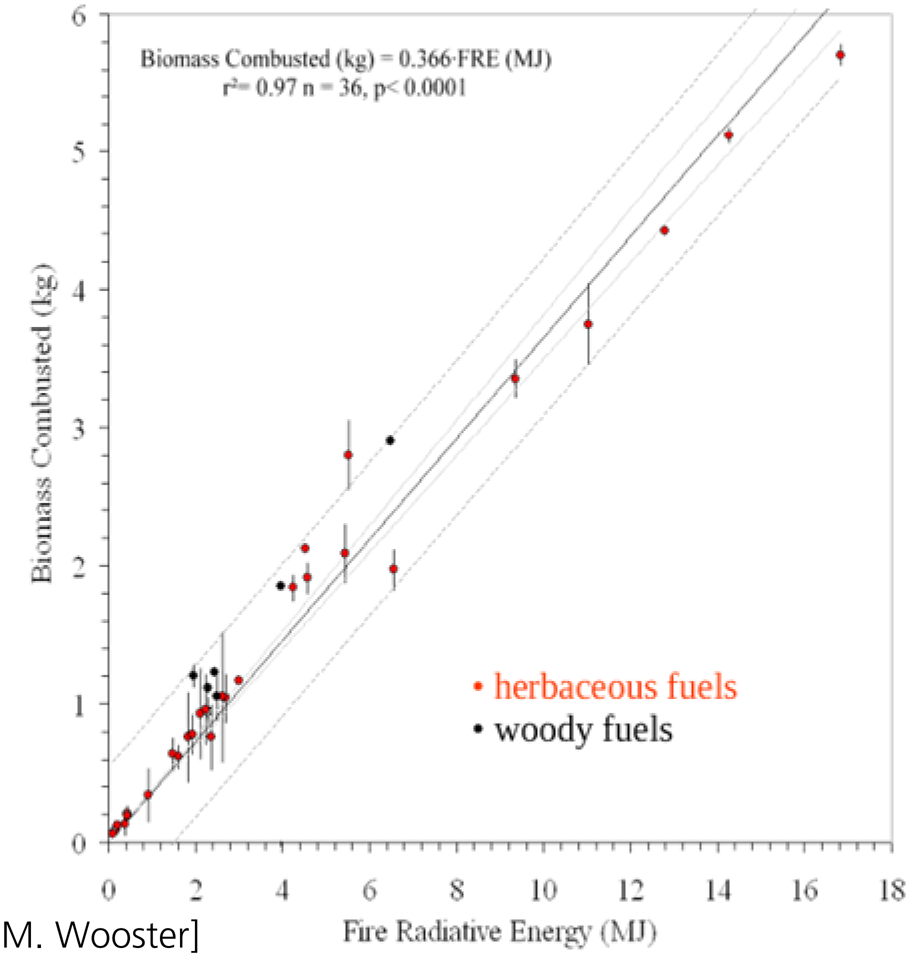
- Close relationship between amount of combusted biomass and fire radiative energy

FRE

cellulose

$$(C_6H_{10}O_5)_n + 6.n.O_2 \rightarrow 5.n.H_2O + 6.n.CO_2 + Q$$

Gas emission



[Courtesy of M. Wooster]

Instruments

- WAOSS-B (Mars96,BIRD) and HSRS (BIRD)

[Images: DLR]

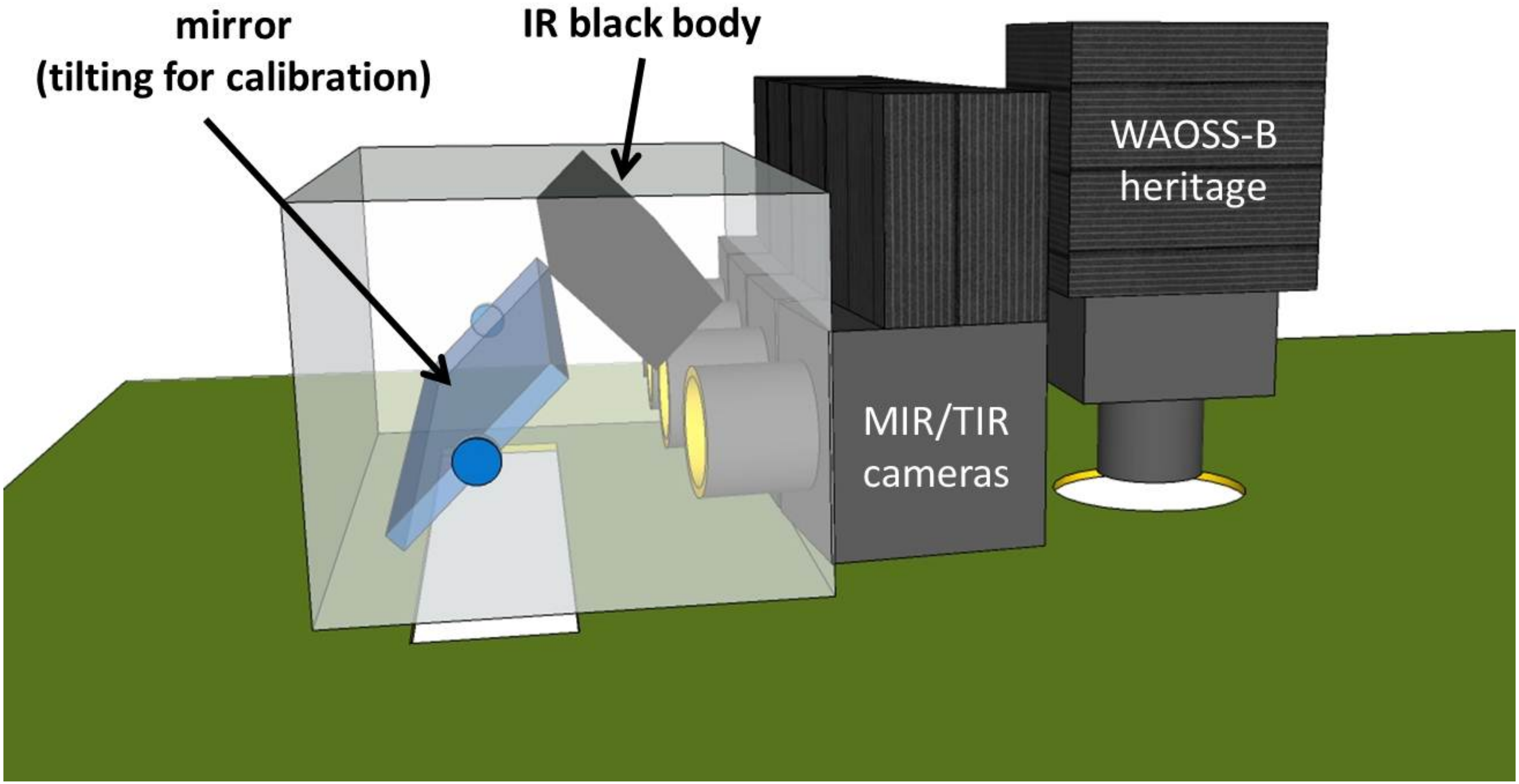
Instruments – Sensor Modifications

- WAOSS-B heritage
  - Based on WAOSS-B (BIRD satellite mission)
  - Larger FOV for wider swath and better temporal resolution
  - Higher number of pixels to increase spatial resolution while keeping large swath
  - Descoping of electronics, allocate data compression to on-board computer

Instruments – Sensor Modifications

- MIR/TIR Sensor
  - Adapt proven HSRS concept flown on BIRD and chosen as basis for FUEGOSAT sensor
  - Advancement:
    - Combine MIR/TIR optics and cooling system
    - One readout electronics for all sensors

Instruments - Accommodation



Instruments - Characteristics

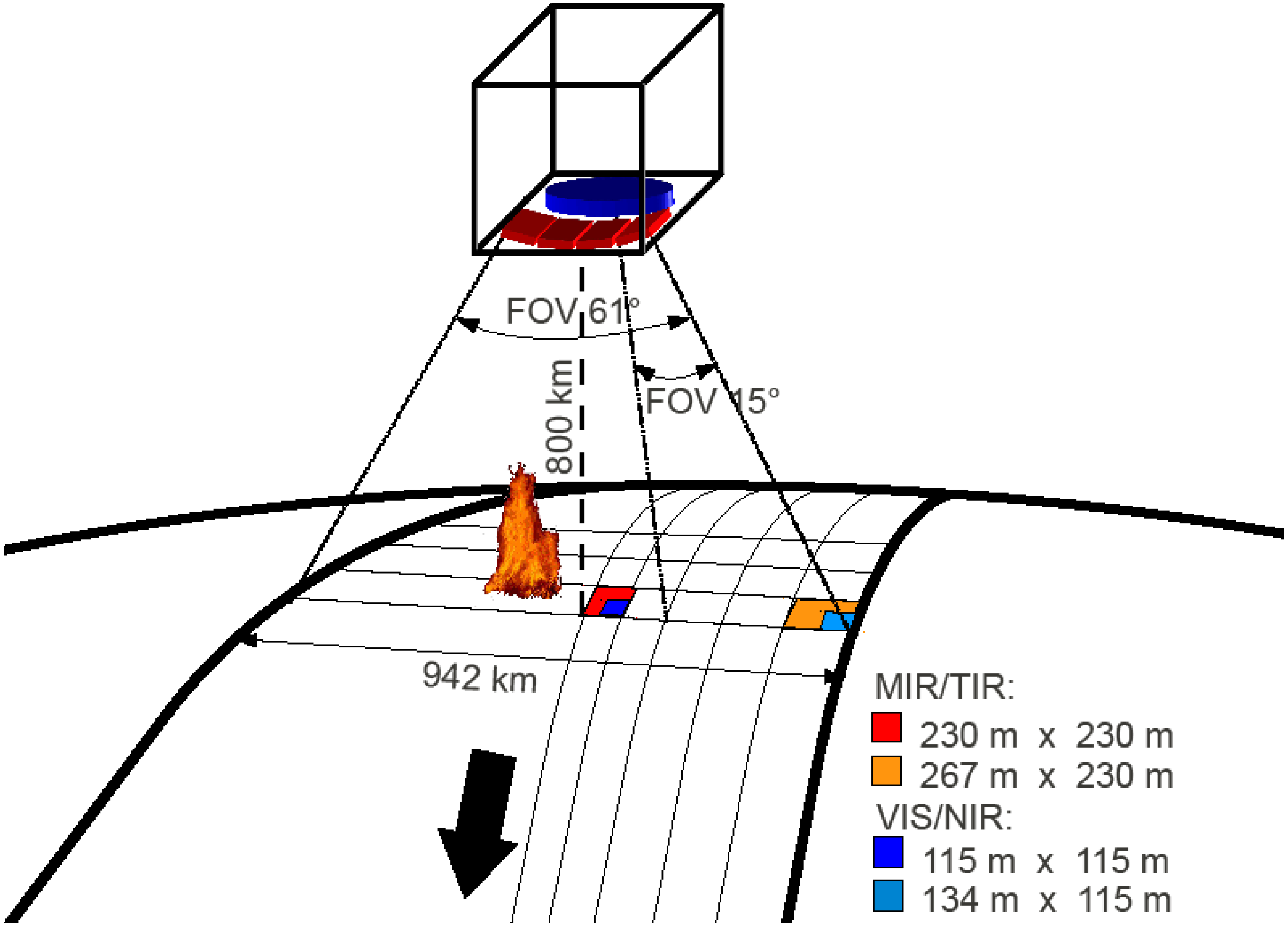
	4 x MIR/TIR	WAOSS-B	WAOSS-B herit.
Wavelength range	3.45-4.15 μm 10-12 μm	0.60-0.67μm 0.84-0.90 μm	0.60-0.67μm 0.84-0.90 μm
Number of pixels	2x512 (stag.)	2880	8192
Pitch	30 μm	7 μm	6.5 μm
Field of view	15.245° (each)	50°	60.979°
Swath width	235 km (each)	533 km	942 km
Footprint (nadir)	230x230 m^2	185x185 m^2	115x115m^2

Instruments - Characteristics

	4 x MIR/TIR	WAOSS-B	WAOSS-B herit.
Thermal res.	0.2/0.5 K		500 W/(m^2 µm sr)
Aperture	28.70 mm	7.73 mm	16.14 mm
Focal length	57.39 mm	21.65 mm	45.18 mm
Size	15x13x10 cm^3	37x19x22 cm^3	25x14x14 cm^3

Thermal resolution derived from FUEGOSAT final report

Instruments - Measurement Geometry



Instruments – Further Specification

- Enact double acquisition (≈ 4 ms / 40 µs)
  - 4 ms to detect small fires and guarantee high sensitivity
  - 40 µs to prevent saturation due to large/intensive fires
- Black body calibration for the IR channels (300 K)
- Emergency release mechanism for mirror

Instruments – Further Specification

- Scientific payload mass: 78.0 kg (+25%)
- Data rate: 15.3 Mbps uncompressed
- Total power consumption: 148 W
- Development time:
  - 4 years for MIR/TIR
  - 3 years for WAOSS-B heritage

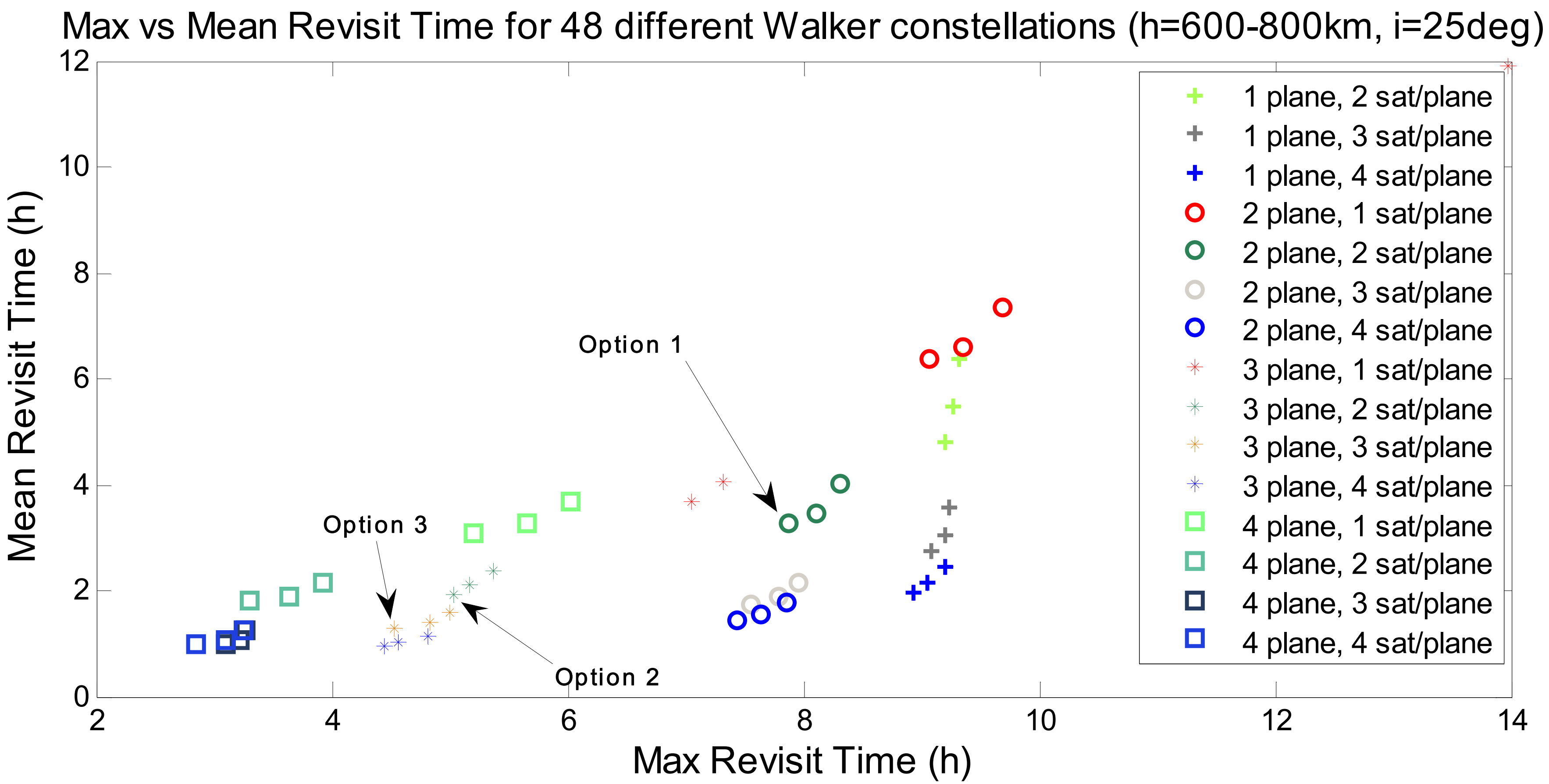
Instruments - Potential Errors

- Statistical error due to instrument noise
  - Conservative estimate for a small fire: $\sigma_{FRP} \approx 3.4\%$ (burning area 25×25 m², $T \approx 500K$)
- Systematic errors will be dominant
  - Instrument calibration accuracy (3 K)
  - Insufficient sub-pixel information on area fraction burning
  - Uncertainty on emissivity
  - Influence of aerosol load and clouds on radiative transfer

Orbit trade space exploration (1/2)

- Constellation needed for high revisit time
- Near-equatorial orbits (25°)
- 81 different Walker constellations analyzed
  - Altitude: [600,800] km, step = 25km
  - #Planes: 1,2,3,4
  - #Sats per plane: 1,2,3,4
- Metrics to consider for selection
  - Mean Revisit Time
  - Max. Revisit Time
  - #Sats and #Launches (3 sats/launch) as a proxy for cost

Orbit trade space exploration (2/2)



Orbit selection

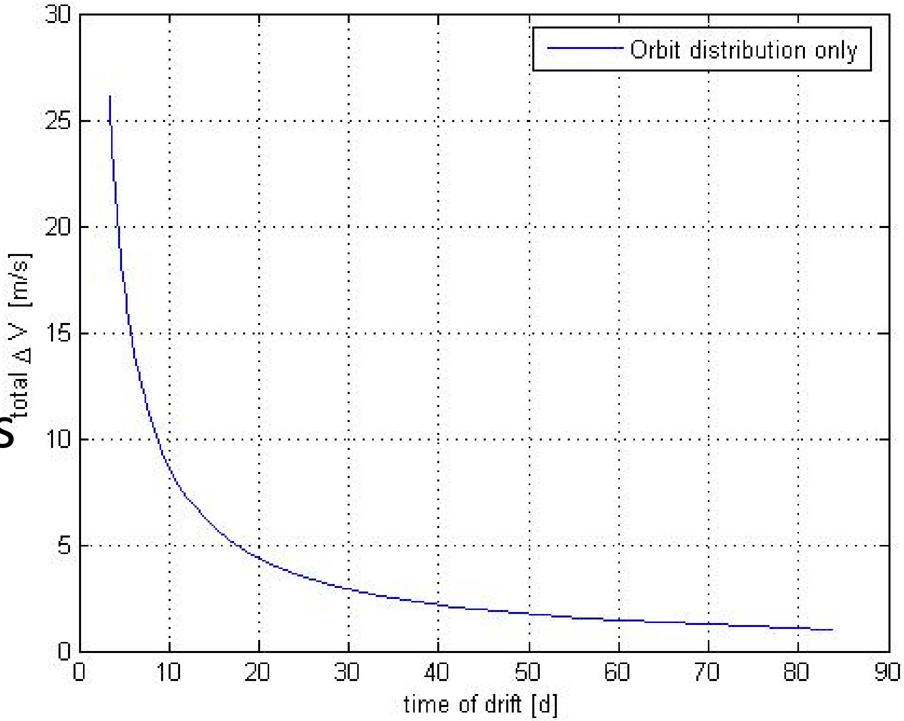
Option	#sats	#planes	#sats/plane	#launches	Mean revisit Time (h)	Max revisit time (h)
1	4	2	2	2	3.3	7.9
2	6	3	2	2(*)	1.9	5.0
3	9	3	3	3	1.6	4.5

(*) One launch saved thanks to RAAN change maneuver

- 3 options pre-selected:
    - Option 3 preferred
    - Options 1 and 2 descoping
    - Option 2 nominal design scenario in this presentation (most constraining design)

Orbit insertion (change in anomaly)

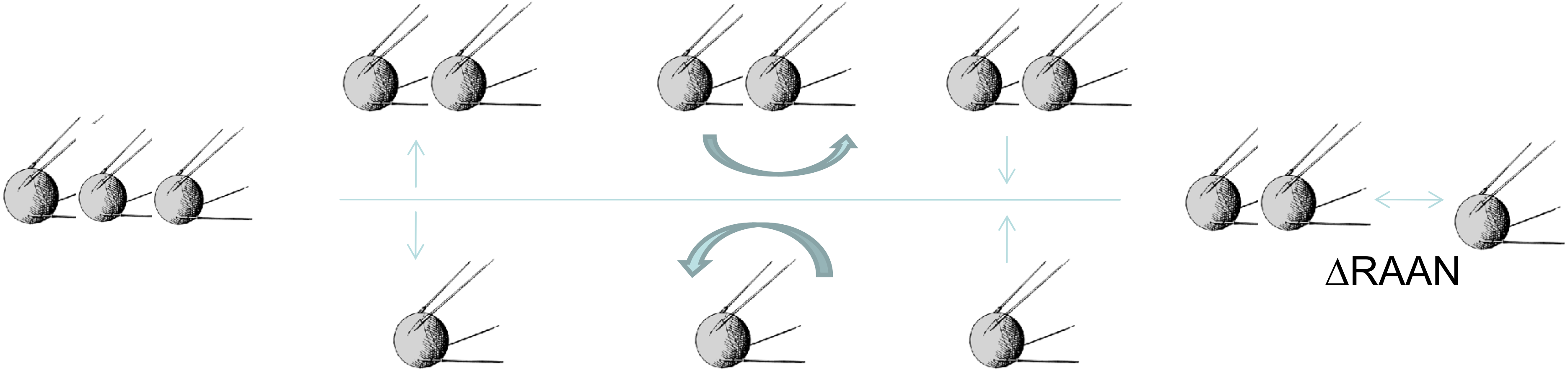
- 3 satellites are injected at the same orbit by LV
- Need to be evenly spaced in anomaly (120 deg)
- Can be achieved exploiting difference in orbital velocity at slightly different altitudes
- Δh~10km ➔ 120 deg in true anomaly in ~ 2 weeks
- Total maneuver cost: **10 m/s ~ 1 kg propellant**



Saving launch cost (Option 2 only)

- Option 2 requires 3 different orbital planes
- RAAN change allows 3 orbital planes by 2 launches
- Accomplished by utilizing differential precession of the ascending node (J_2 perturbation) at different orbital altitudes

$$\dot{\Omega}_{J_2} = -2.06474 \cdot 10^{14} a^{-7/2} \cos i \left(1 - e^2\right)^{-2}$$



Hohmann transfer

J_2 Drift

Hohmann transfer

Saving launch cost (for Option 2)

- Dh=+/- 130 km allows a DRAAN = 120 deg in ~ 8month
- “temporary” orbits

  (h1=670km, h2=930km)
- 930km: radiation environment should be studied
- Total maneuver cost:

  137 m/s ~ 22.1 kg propellant

Propulsion requirements: ΔV budget

Task	ΔV	Unit
Orbit Insertion in plane (10 days)	10.0	m/s
Orbit plane change (Option 2 only)	148.0	m/s
Orbit Maintenance (7 years)	6.0	m/s
De-orbit (800km, 25 years)	80.0	m/s
Margin (15%)	14.4 (36.6)	m/s
Total ΔV (for Option 2)	110.4 (280.6)	m/s

Chemical
Hydrazine
Monopropellant

Thrust range: 8-24.6 N
Specific Impulse: 224-230s
Mass: 0.395kg
Lifetime: 10h
EADS Astrium

Propulsion subsystem layout

Component	Mass [kg]
20 N thruster	0.4
Propellant mass (Option 2)	15.6 (39)
Tank (EADS Bladder type, 39 litres)	8.5
He-Pressurization system (2.4 litres)	2.0
fuel line + pyro & check valve	1.0
20% Margin (Option 2)	5.0 (9.3)
Propulsion subsystem mass (Option 2)	**30.0 (55.9)**

Peak power consumption (valve open): 9.5W

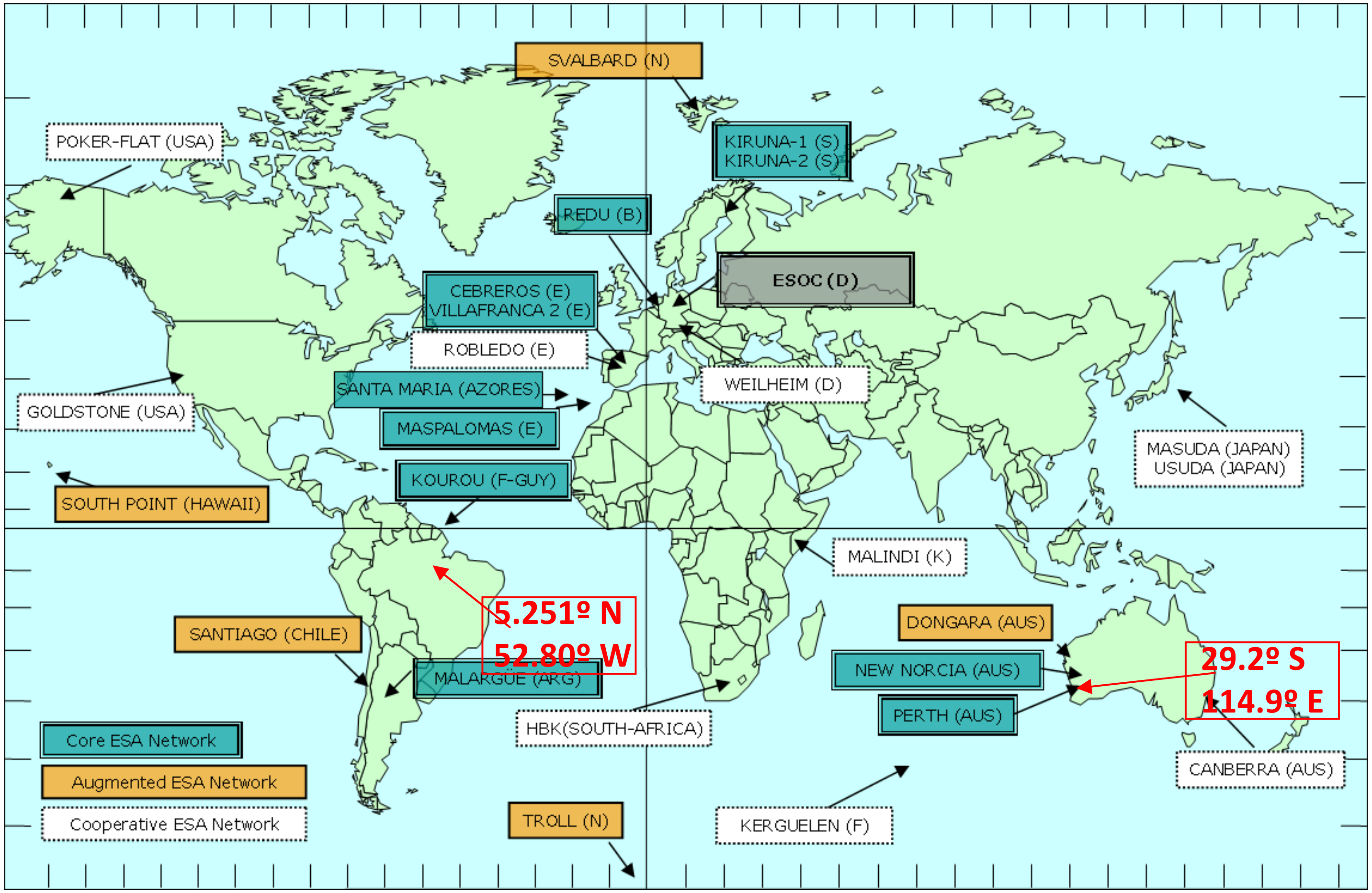
Communications subsystem

- Data accumulated in one day:760Gbit with x2 lossless compression
- Average total access time per day for 1 satellite: 2.64h
- Required data rate: Rb_{min} = 79.9Mbps

- X-band 8.45GHz for data downlink at **85Mbps**
  - Low gain antenna
  - QPSK transceiver

- S-band (2.05 GHz) for TT&C
  - 2x Omnidirectional antenna
  - 2 x BPSK transceiver

Available Ground Stations



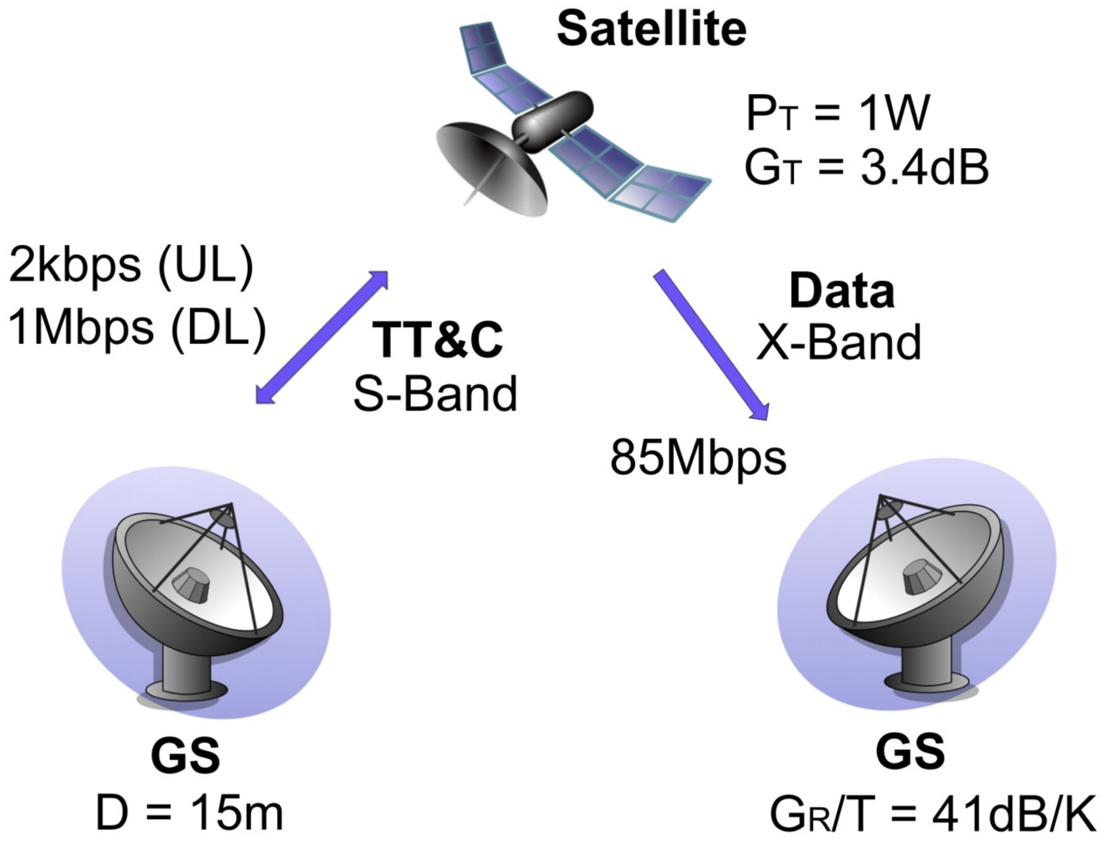
ESA Tracking stations network (ESTRACK)

Source: ESA

Link budgets

Uplink	
$EIRP_{GS}$	104.7 dBm
G_{sat} (S-Band)	0 dB
R_b	2kbps
Margin	**66.6 dB**

Downlink	
P_{sat}	1 W
G_{sat} (X-Band)	3.4 dB
G_{GS}/T	41 dB/K
R_b	85 Mbps
Margin	**8.6 dB**



Satellite

P_T = 1W
G_T = 3.4dB

2kbps (UL)
1Mbps (DL)

TT&C
S-Band

Data
X-Band

85Mbps

GS
D = 15m

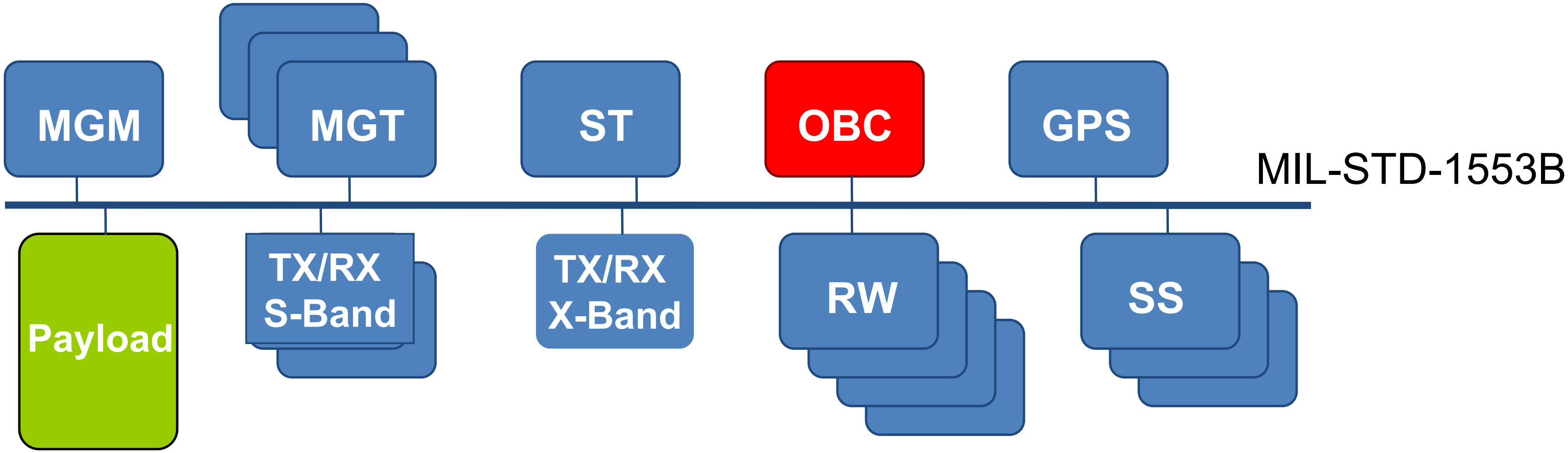
GS
G_R/T = 41dB/K

Attitude Determination and Control Subsystem

- 3-axis stabilized platform for 0.1 deg att. control
- Attitude control:
  - 4 reaction wheels (sized for max disturbance torque)
  - 3 magnetic torquers (for RW desaturation and rough control in safe mode)
- Attitude determination
  - Star tracker
  - 3 Sun sensors (coarse attitude control)
  - 3-axis magnetometer
  - GPS receiver (orbit determination/ranging)

On Board Data Handling

- On Board Computer Proton 400k (10W)
- On Board Data Storage driven by requirement to store data through 1 orbit (35Gb ➔ 64Gb)



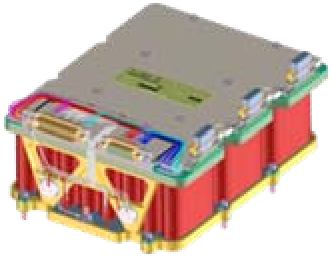
Power budget

Component	Avg power (W)	Duty cycle	Typical power (W)
Payload	148.0	100%	148.0
S-band transceiver+antenna	13.0	15%	2.0
X-band transceiver+antenna	31.0	15%	4.7
On board computer	10.0	100%	10.0
Reaction wheels	10.0	100%	10.0
Magnetic torquers	3.1	100%	3.1
GPS receiver	20.0	100%	20.0
Star tracker	8.0	100%	8.0
Sun sensors	2.0	100%	2.0
3-axis magnetometer	0.6	100%	0.6
Power subsystem	41.7	100%	41.7
TOTAL			250.0
Margin(10%)			25.0
TOTAL with margin			**275.0**

Electrical power subsystem

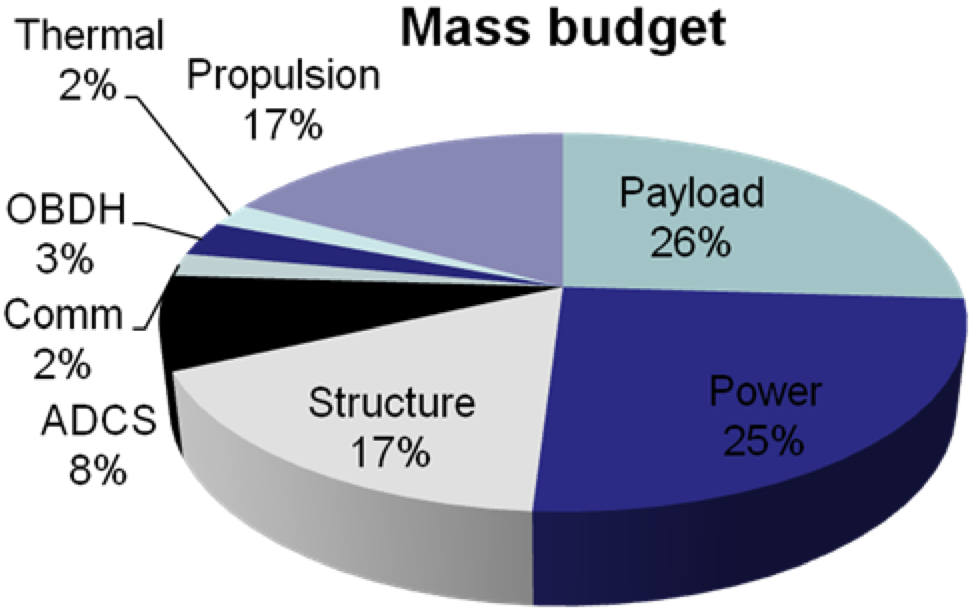
Solar array sizing		
Required power	275.0	W
Efficiency solar cells (Multi-junction)	22%	
Power output	300.7	W/m^2
Loss factor due to solar illumination	0.32	
Loss factor from solar array to power distribution	0.85	
Power output BOL	81.4	W/m^2
Yearly degradation	1%	
Power output at EOL	78.6	W/m^2
Area solar array	3.5	m^2
mass solar array	5.9	kg

Batteries sizing		
Eclipse time	0.583	h
DOD	10%	
Efficiency	0.9	
Capacity	1782.1	Wh
Capacity per battery	467	Wh
Specific mass (Li-Ion)	103.8	Wh/kg
Total battery mass	17.2	kg
# batteries	3.8	#

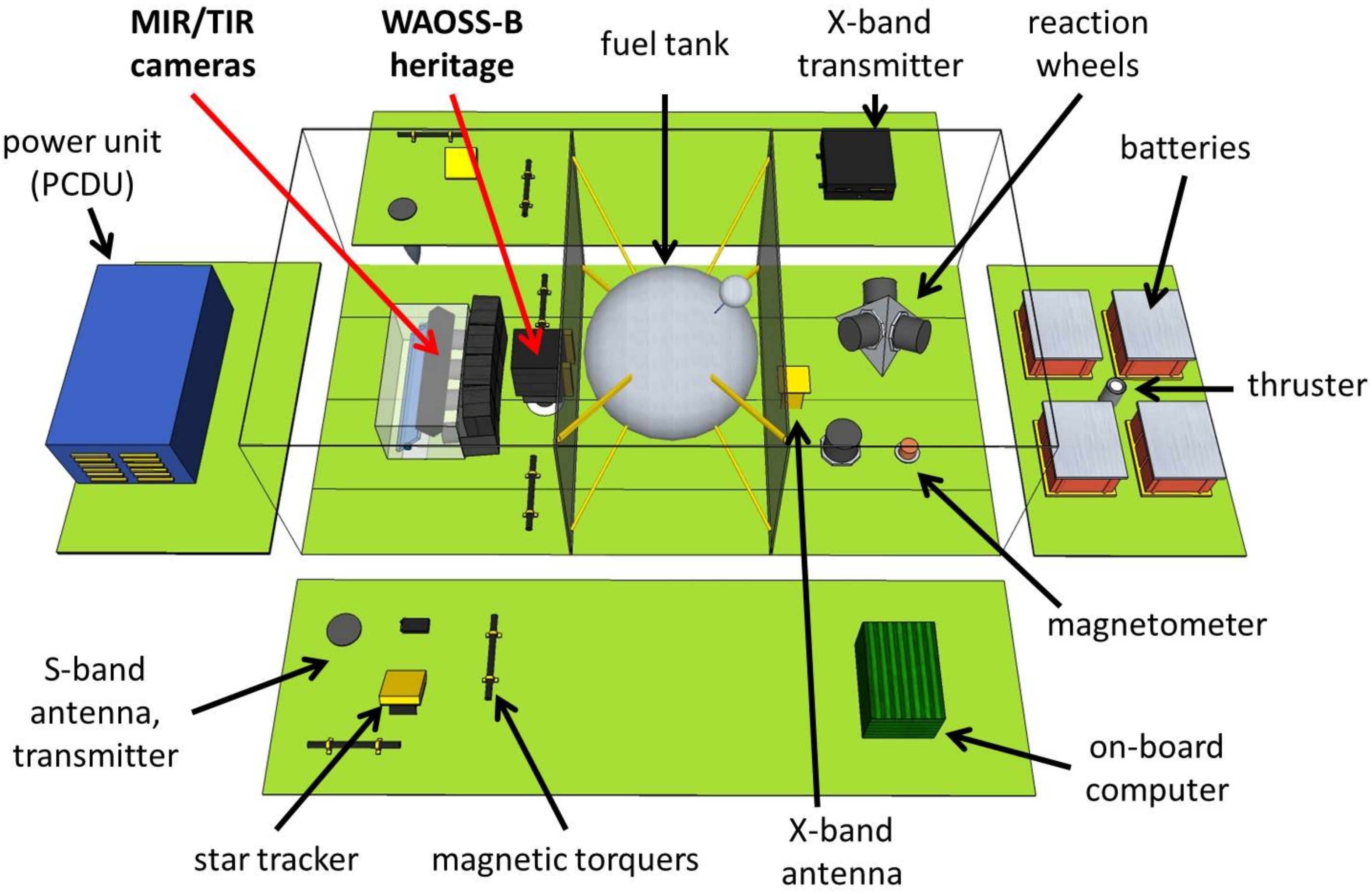


Mass budget

Subsystem	Mass (kg)	Mass (%)
Payload	74.8	26%
Power	71.9	25%
Structure	48.9	17%
ADCS	23.0	8%
Comm	5.8	2%
OBDH	8.6	3%
Thermal	5.8	2%
Propulsion	55.9	17%
Total	**294.7**	**100%**
20% Margin	**58.9**	
Total + margin	**353.6**	

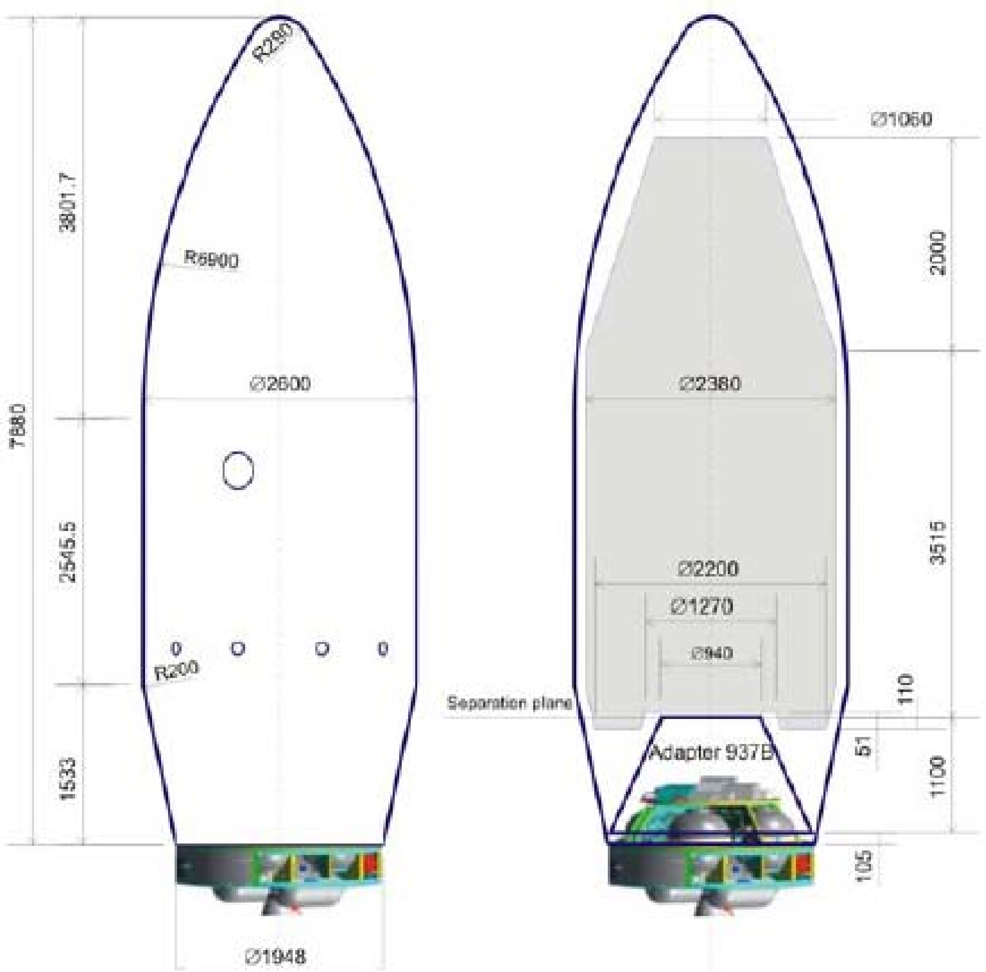


Satellite configuration

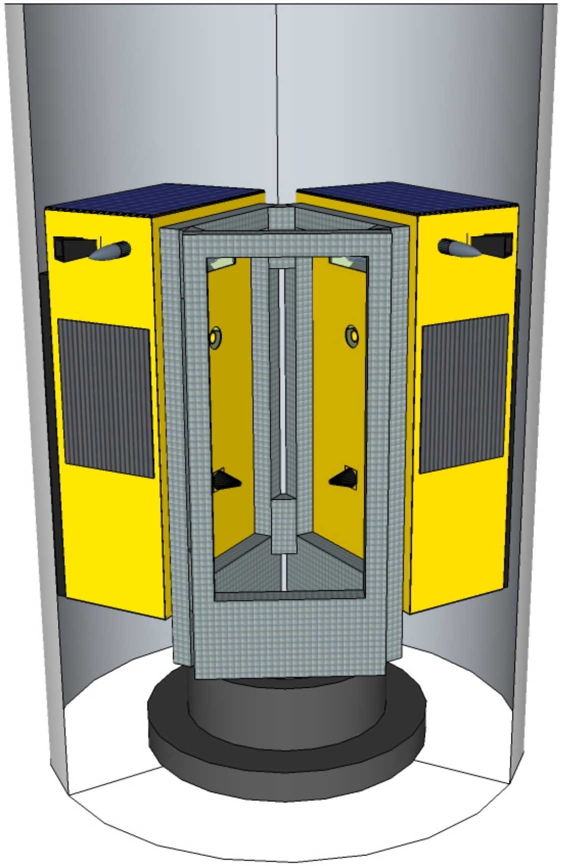


Launch vehicle selection: VEGA

- Performance at 800 km and 25°: 1900 kg
  - 3 sat. 345 kg each.
- Price: 35 M€
- Launch site: Kourou
  - Satisfies reqs. of latitude and azimuth
- Backup option considered: PSLV (similar volume)

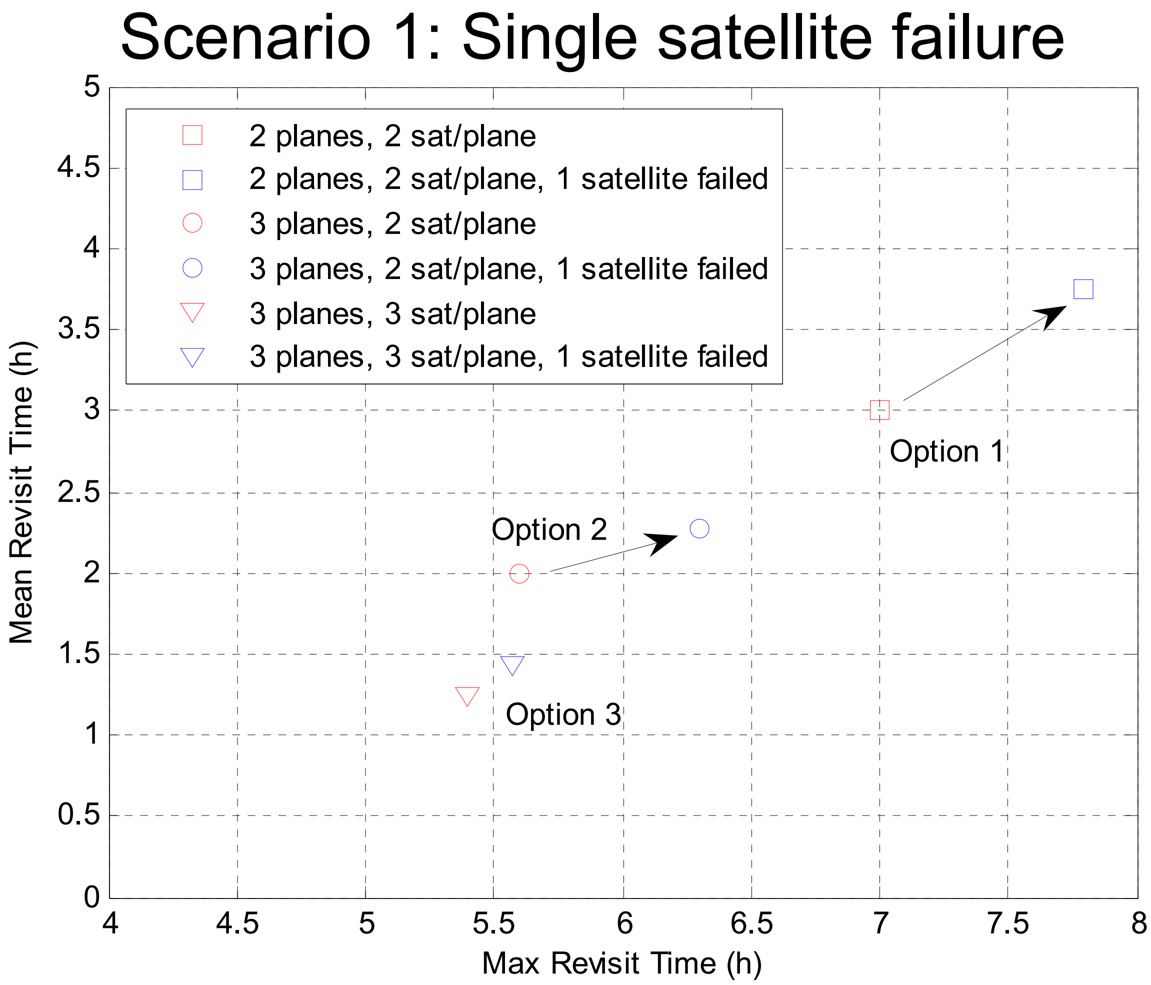


Fitting Satellites in VEGA Rocket

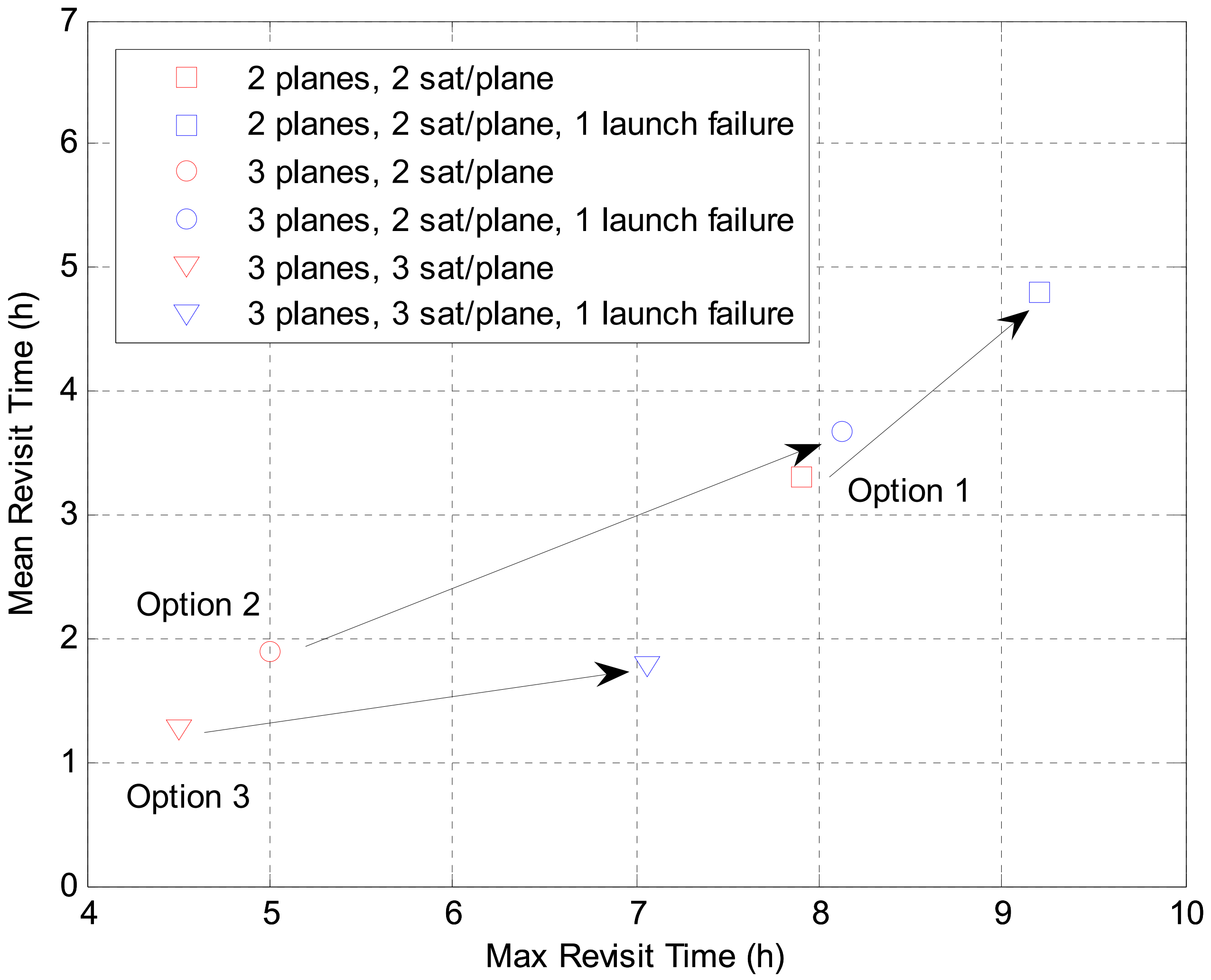


➔ Launch of 3 VESTA satellites with one launcher possible

Risk analysis (1/2)



Risk analysis (2/2)



Technology Readiness Level

Subsystem /critical component	TRL	Comment
ADCS	5	Existing, costumisation needed
Data handling & Onbord computer	6	Existing
Instruments		
WAOSS-B Heritage	5	Existing instrument with modification
MIR/TIR Sensor	3	Existing components, rearranging in new design
Propulsion	6	Readily available, space heritage
Power		
Batteries	6	Readily available, space heritage
Solar arrays	5	Technology available, only shape costumization needed

Mission Schedule

- **Phase A** (2 yr)
  - Mission definition (1 yr)
  - Technology development (2 yr)
- **Phase B** (2 yr)
  - System definition (1 yr)
  - Preliminary design (1 yr)
  - Technology develoment (2 yr)
- **Phase C** (1.5 yr)
  - Final Design (1.5 yr)
- **Phase D** (1.5 yr)
  - Stagered manufactured of payloads (1.5 yr)
  - Spacecraft (1 yr - begining)

Cost estimates

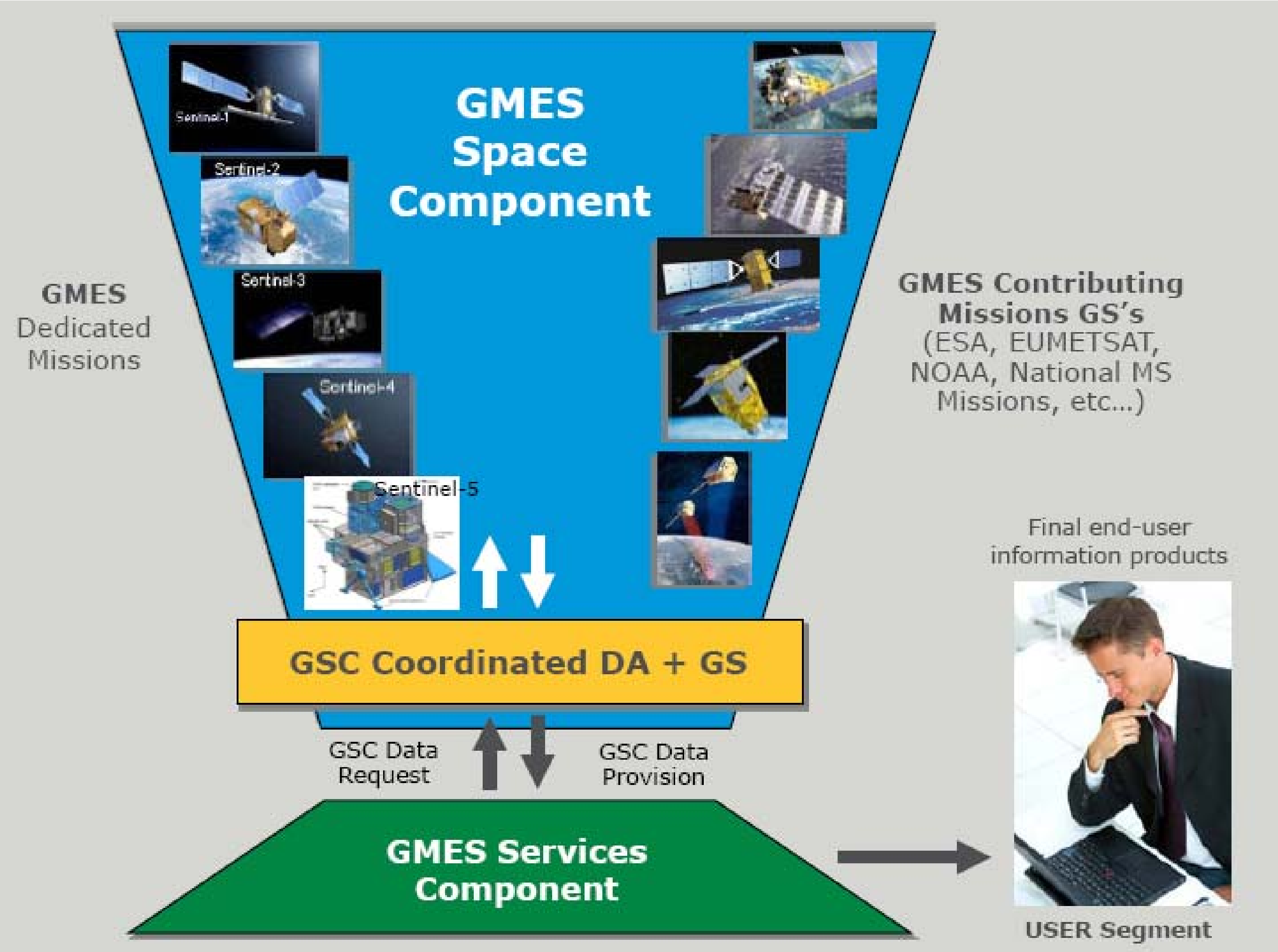
	Option A	Option B	Option C
Payload (1st unit)	33	33	33
Bus (1st unit)	52	52	52
1st satellite	85	85	85
2nd satellite	47	47	47
3rd satellite	44	44	44
4th satellite	42	42	42
5th satellite		42	42
6th satellite		42	42
7th satellite			42
8th satellite			42
9th satellite			42
Launches (2)	70	70	105
Operations (7 years)	70	70	70
SUBTOTAL	443	527	687
Margin (20%)	89	105	137
TOTAL	**532**	**632**	**825**

- Based on CER given in Wertz, 2000
- Include R&D and TFU costs
- Learning curve
- Launch costs
- 7 yrs of operations
- Costs converted from FY04$k into FY10M€

Data products

- Level 0
  - Detector counts
- Level 1
  - Time-organized single sensor radiances for each band
  - Instrument housekeeping data
  - Radiometric and geometric calibration coefficients
  - Geo-referencing parameters (ephemeris data)
- Level 2
  - Interpreted geophysical parameters (Fire Radiative Power, Fire Temperature, hot spot extension, NDVI)

Data distribution



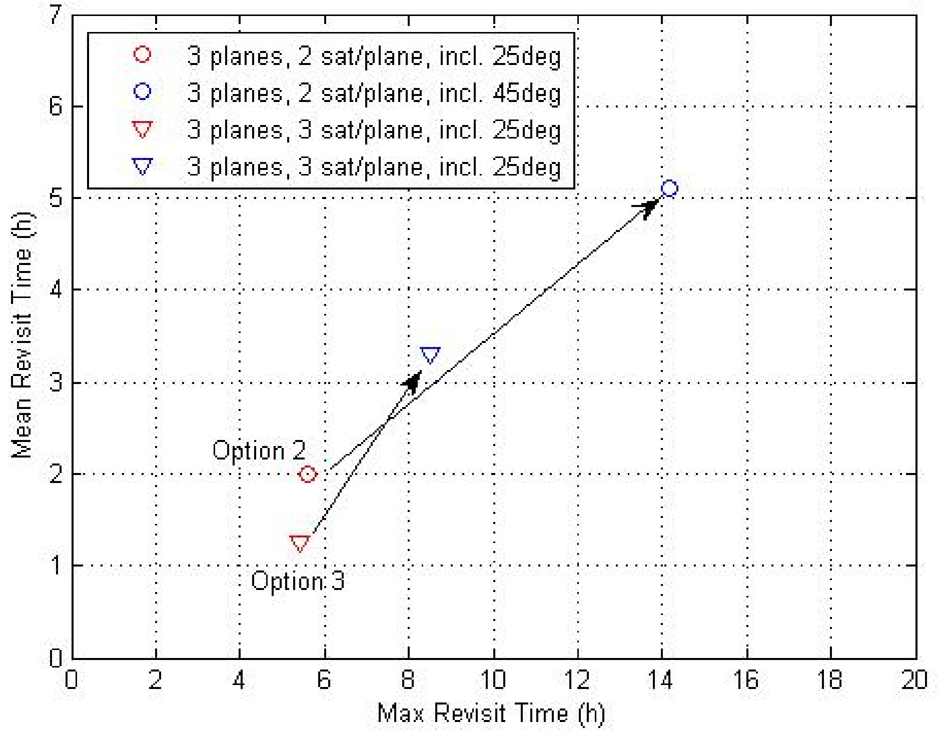
Validation and Assimilation

- Vicarious cross-correlation between Vesta satellites
- Vicarious validation with polar satellites (MODIS)
- Validation with in-situ measurements (Ground truth assessment of burned biomass)

- Data can be included into climate models to account for the impact of fires which cannot be modeled.

Mission “extension” assessment

- Studied an extended mission with coverage in +/- 45 deg
- Added scientific value
  - +10% in coverage of global CO_2 emissions
- Added societal value
  - Fire detection in Mediterranean basin (Spain, Italy, Greece)



Conclusion

- Vesta could measure fire radiative power with sufficient spatial, radiometric and temporal resolution to reduce uncertainty of CO_2 emissions.
- Vesta could sufficiently monitor FRP to provide data for Aerosol release and calibration of geostationary sensors.
- A constellation of four satellites could still provide more accurate data than current missions but would provide reduced temporal coverage.

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Thank you for you attention!

References

- Zhu05: Zhukov et. al, 2005
- And01: Andrea and Merlet 2001
- [Woo05]: Wooster et.al, 2005
- [Den06]: Dennison et.al, 2006 (Remote sensing)
- [NOAA]: Source:NOAA/National Weather Service Climate Prediction Center
- [Doz81]: Dozier, 1981: Bi-spectral Technique for retrieving temperature and area of sub-pixel hot spots