Appendix M

Use of ThermXL & THERMICA in THERMAL CONTROL ENGINEERING for CNES BALLOONS VEHICLES

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Abstract

Different kinds of stratospheric & troposheric terrestrial aerostats and planetary balloons are developed and used by CNES in order to answer the various demands of the international scientific community. Each type of terrestrial balloon has its own flight domain. It is supposed to fly all over the Earth, to be launched at any time and from everywhere. Hence the aerostats can see various external thermal environments.
The thermal aspects are taken into account in the overall design and verification process of the aerostat (balloon envelope, operational and payload gondolas). The balloon's thermal environment has also a significant effect on the aerostat in-flight behaviour (flight physics) and is of first importance for long-duration flights due to the limited electrical power available. Thus, thermal models are used during balloon campaigns. The results of the thermal and energy balance (for a predicted trajectory) are one of the information considered to decide on the feasibility of a flight.
The contents of the presentation are as follows:

- Overall presentation of CNES aerostats
- Terrestrial aerostats thermal environment
- Thermal engineering (main concerns)
- An example of thermal analysis / ConcordIasi campaign (long duration flight)
  Prediction of gondolas autonomy in terms of electrical energy: presentation of the thermal models (use of THERMICA and ThermXL tools)

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CNES BALLOON VEHICLES

Thermal Control Engineering

Use of ThermXL & THERMICA

Gaël PAROT

CONTENTS

- Overall presentation of CNES's aerostats
- Aerostat thermal environment on Earth
- Thermal engineering (main concerns)
- An example of thermal analysis / Concordiasi project, McMurdo 2010 campaign (long duration flights)
  - Prediction of gondolas autonomy in term of electrical energy
  - Presentation of the thermal models, elaborated with THERMICA and ThermXL

CNES aerostats

Aerostats are mainly used for scientific missions :

- To study the Earth atmosphere (components, motion): troposphere and stratosphere
- For the study of sciences of the universe (astronomy, planets exploration)

Different kinds of balloons have been developed by CNES in order to answer the various demands of the scientists

The Earth balloons derive into 4 families:

- BSO, or “Ballon Stratosphérique Ouvert” / Zero Pressure balloon
- MIR, or “Montgolfière InfraRouge” / Infrared montgolfiere
- BPS, or “Ballon Pressurisé Stratosphérique” / Super Pressure Balloon
- BTT, or “Ballon Traceur Troposphérique”

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BSO (Zero Pressure Balloon)

Main characteristics:

- The biggest !
- Volume is from 3000 to 1200000m^3
  the envelop surface of the biggest BSO is as large as 14 soccer fields
- Payload up to 2 tones
- Flight duration : ~several hours to a few days
- Elevation : 20 to 43 km
- Filled with helium

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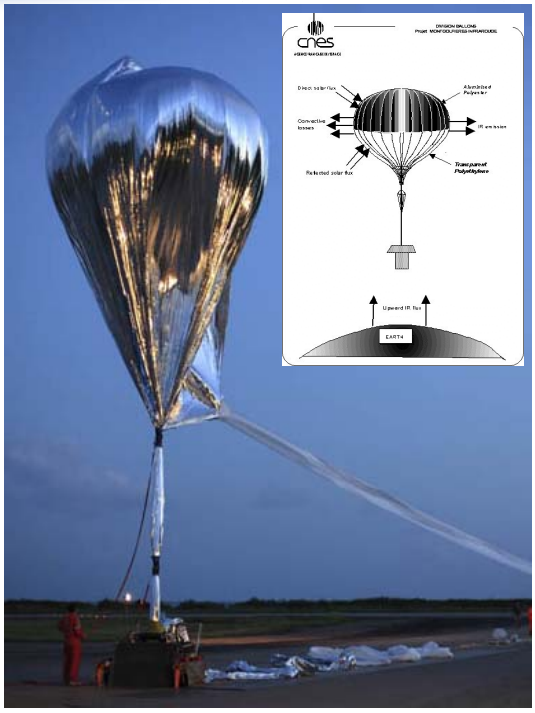
MIR (IR montgolfiere)

Main characteristics:

- Hot air balloon
- The upper part is aluminized in order to capture the IR ascending heat flux (lower part is translucent to the IR flux)
- Volume is 45000m³
- Payload is 40 to 60kg
- Flight duration : ~several weeks / up to some months
- Elevation : 28 to 30km during the day, 18 to 22km during the night



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BPS (Super Pressure Balloon)

Main characteristics:

- Pressurized balloon
- Different sizes: 8.5m, 10m and 12m diameter
  16 m under development
- Payload is up to 40kg
- Flight duration : up to 3 months, and more
- Elevation : 18 to 20km

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BTT: BPCL, Nano Balloon and the Aeroclipper

Aeroclipper

Aeroclipper main characteristics :
Under development
Specificity is the use of a “guiderope”
Will be used to investigate large oceanic areas (dedicated to measurements in both atmosphere and sea)

BPCL

BPCL main characteristics :
Pressurized balloon
Diameter is 2.5m
Gondola located inside the balloon
Flight duration : up to 1 month
Elevation : 1 to 2km

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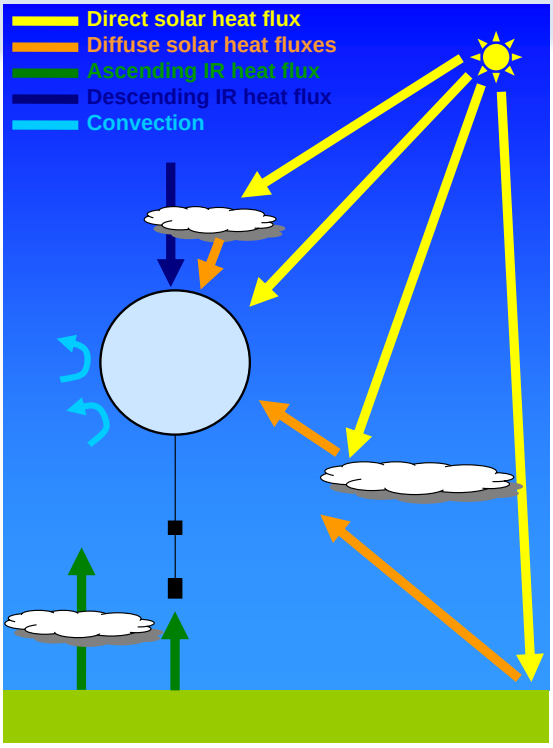
Terrestrial external thermal environment

As aerostats may fly all over the Earth and for at least a few days, they would be submitted to significant variations in term of thermal environment:

- Pressure / temperature profile
- Solar radiation: direct and diffuse heat fluxes (albedo included)
- Ascending and descending IR heat fluxes

They have to be sized in order to be reliable regarding the significant thermal environment variations at the day/night and flight scales



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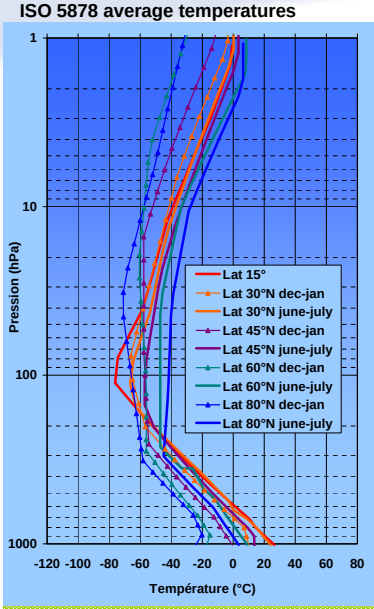
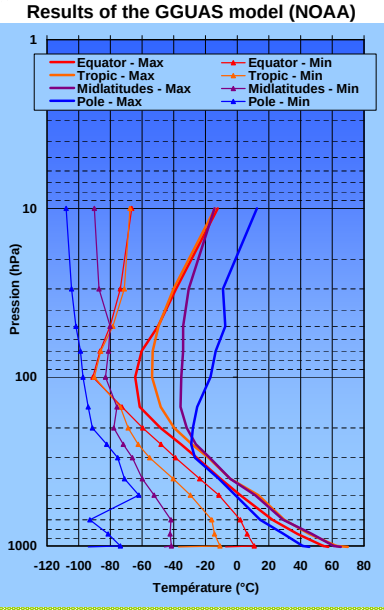
Pressure / temperature profiles

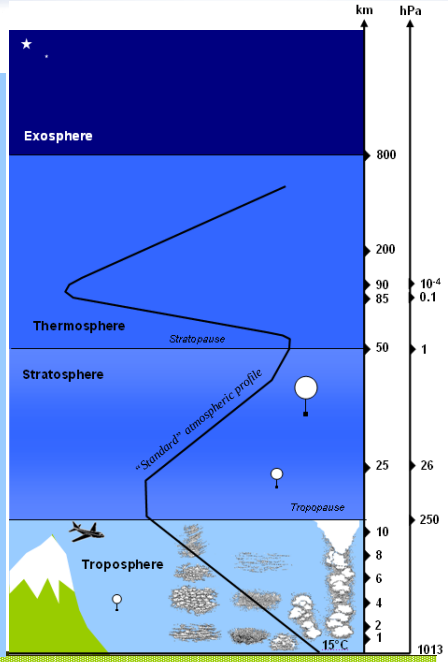
Examples of ATMOSPHERIC PROFILES:

ISO 5878 average temperatures



Results of the GGUAS model (NOAA)





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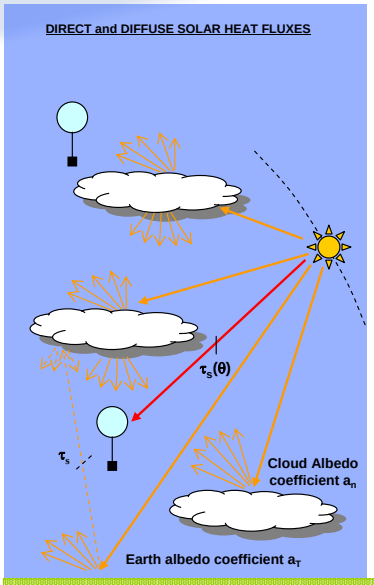
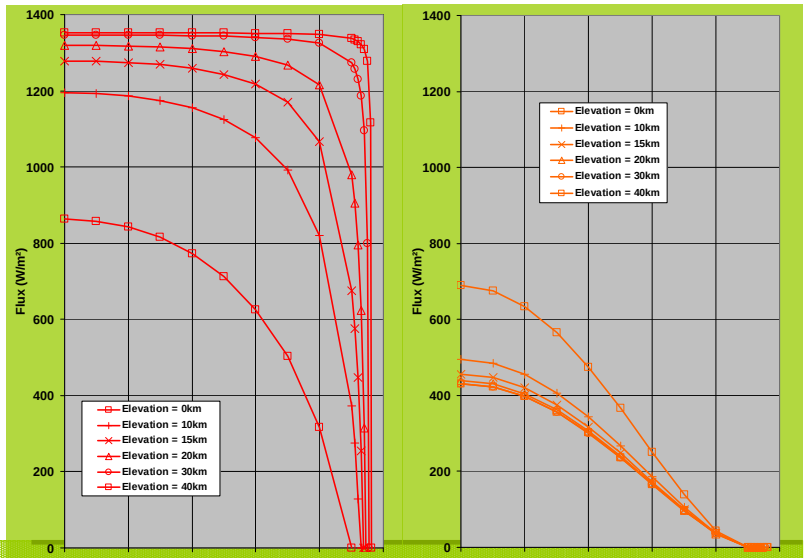
Solar radiation

Examples of SOLAR HEAT FLUXES (clear sky)

Direct solar heat flux (Co=1355W/m²) **Albedo (a_T=0.8)**





a_T from ~0.03 for the ocean to ~0.9 for snow
a_n from ~0.1 for stratus to ~1 for cumulonimbus

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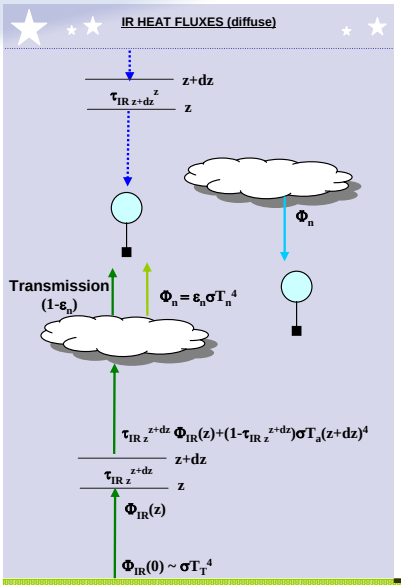
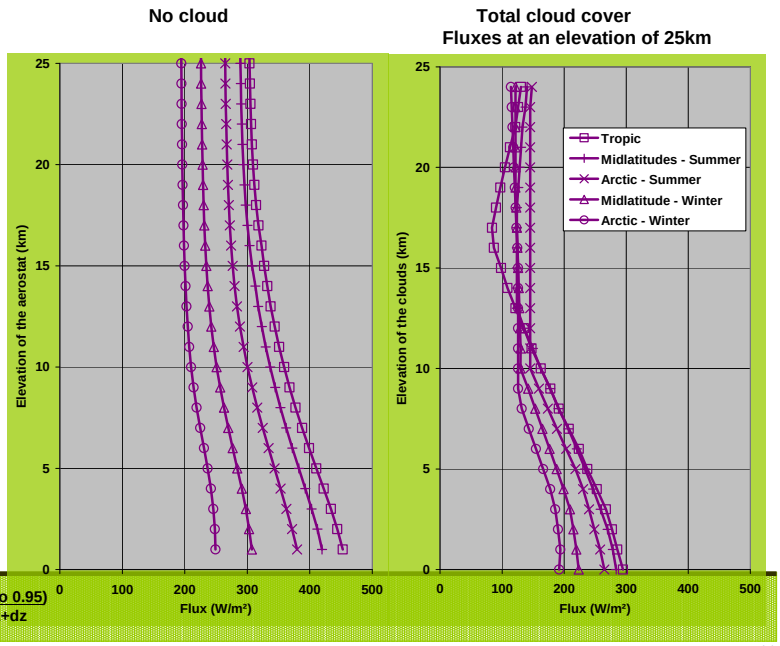
IR radiation



Examples of ASCENDING IR HEAT FLUXES



ε_n: cloud emissivity in the IR wavelength (from ~0.7 to 0.95)
$\tau_{IR\ z}^{z+dz}$: transmission of the air slice between z and z+dz elevations

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Aerostat thermal engineering

Main concerns

- **Balloon**
  - Thermal balance is taken into account in flight physics models
  - CNES In-house dedicated flight physics tools are used, which conjugate thermal behavior of the gas and the envelope within flight physics and gas motion
- **Suspended devices (gondolas as an example)**
  - Thermal science is considered in design and verification process whatever the kind of aerostat and suspended device
  - Use of commercial space thermal softwares
  - i.e.: THERMICA for radiative heat exchanges, ThermXL for heat balance
  - Thermal science plays also an important role for the prediction of gondolas energy autonomy for long duration flights (BPS) → confer next slides (Concordiasi project)

CONCORDIASI

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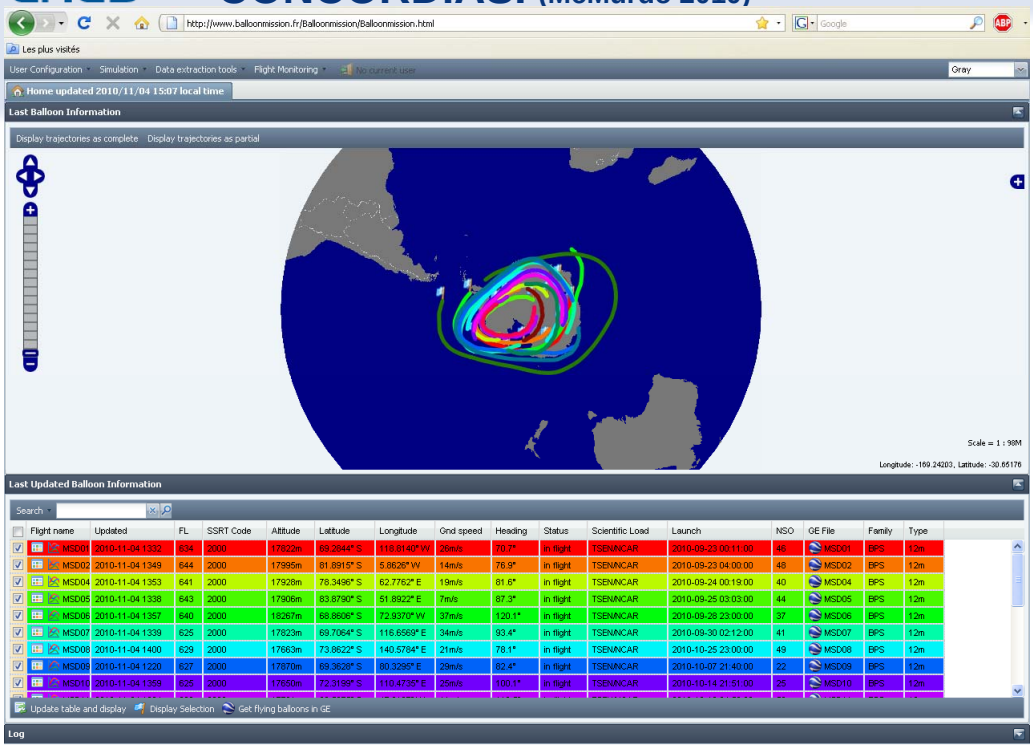
CONCORDIASI (McMurdo 2010)



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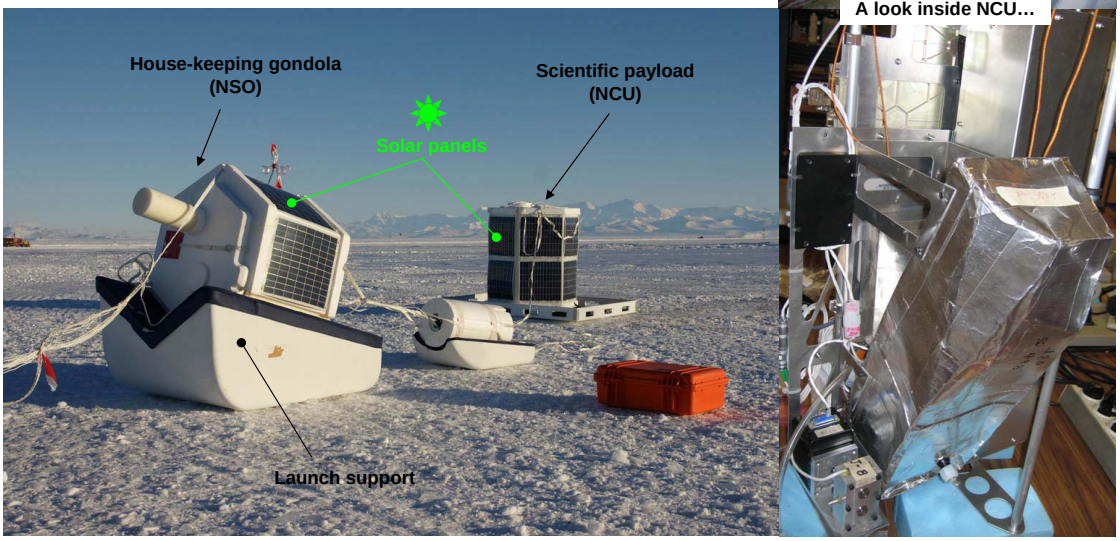
CONCORDIASI (McMurdo 2010)

A look inside NCU…



CONCORDIASI (McMurdo 2010): TCS models architecture

Main inputs for the building of ThermXL models:
- *Geometry*
- *Weight and specific heat for transient computation*
- *Convection heat transfer correlations (inner & outer ones)*
- *Conduction: heat transfer coefficients & thermal conductivity*
- *IR & solar thermo-optical properties*
- *Electrical architecture*
- *Electrical components efficiencies*

Main inputs for THERMICA model building:
- *Geometry*
- *IR & solar thermo-optical properties*

INTERNAL BOUNDARY CONDITIONS
- Thermal heating (instantaneous dissipated P, $T_{threshold}$ …)
- Electric components consumptions

Excel

EXTERNAL ENVIRONMENT
Latitude (°), Time(hh:mm:ss) and Altitude(m)
- Atmosphere profile: Ta, Pa
- IR heat fluxes (ascending & descending)
- Solar fluxes (direct & diffuse)

Thermal TOOL: ThermXL

THERMAL MODEL
Radiation, convection and conduction heat transfers are taken into account

→ Computation of temperatures & the heating power necessary to meet required temperature thresholds

ENERGY MODEL

→ Computation of the accumulator / battery charges

(Balance between consumed power / available solar power)

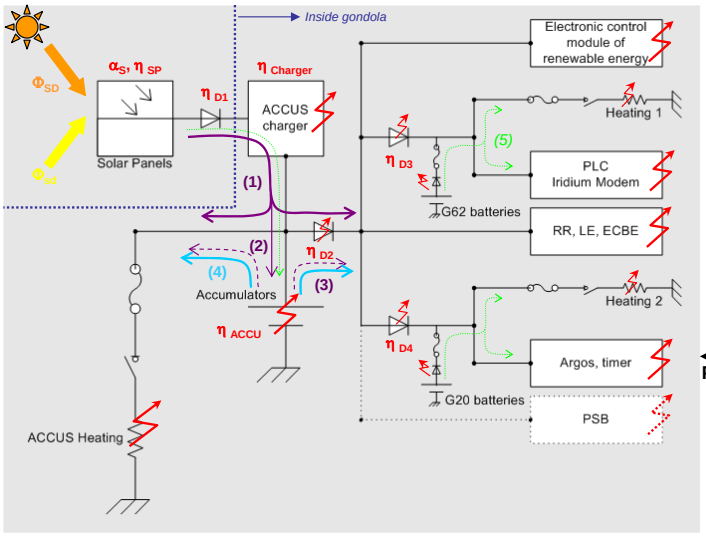
Thermal TOOL: THERMICA

RADIATIVE MODEL

→ Computation of radiative heat exchanges to be used in the ThermXL model

CONCORDIASI (McMurdo 2010): Focus on the electric network

Energy Model



- (1): Day, solar power is used first to feed the equipments and heaters
- (2): Day, solar power is then used to charge the accumulators
- (3): Day, energy provided by the accumulators in case of insufficient sunlight
- (4): Night, electrical energy is provided by the accumulators
- (5): Day or Night, electrical energy is provided by the batteries in case accumulators are discharged (whatever the sunlight) / accumulators fed with 100% available sun power
- Heat dissipating equipments or heaters

T
$P_{Heating}$

Thermal Model

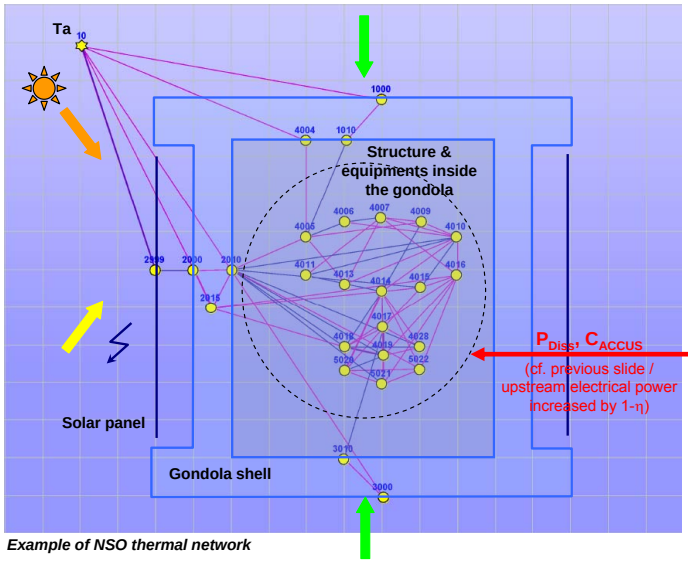
Calculated heating powers as well as temperatures are injected in the "energy" model:

- Accumulator charge = f(T)
- Heaters resistances = f(T)

Example of NSO electric network

CONCORDIASI (McMurdo 2010): Focus on the thermal nodal network (house-keeping gondola)

Thermal model



NCU gondola: 61 thermal nodes
NSO gondola: 27 thermal nodes

- GL conductances (conduction & convection)
- GR conductances
- IR heat fluxes (ascending and descending)
- Solar direct heat flux
- Solar diffuse heat flux
- IR emission

P_{Diss}, C_{ACCUS}
(cf. previous slide / upstream electrical power increased by 1-η)

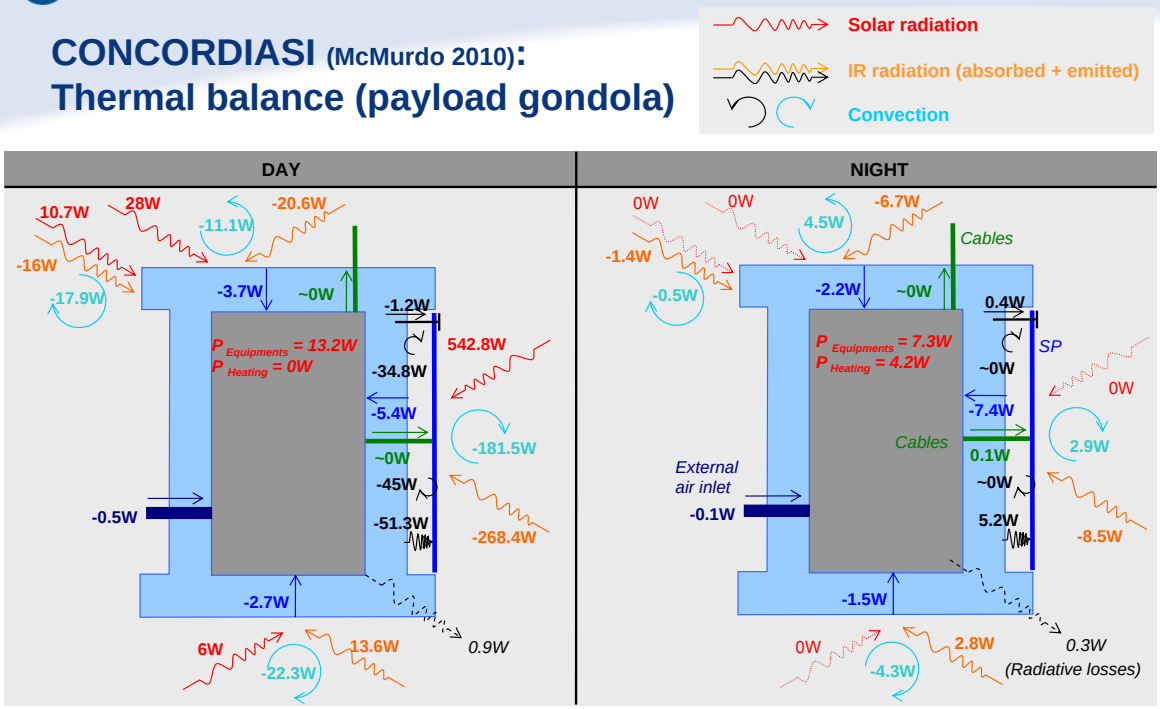
Energy model

Dissipated powers (except heating powers) are injected according to the results of the energy balance:

- Internal heat dissipations depend on the "energy" mode: normal operating / "survival" mode in case accumulators are discharged
- Heating temperature threshold can depend on the accumulator charge (heating logic)

Example of NSO thermal network

CONCORDIASI (McMurdo 2010): Thermal balance (payload gondola)



CONCORDIASI (McMurdo 2010): Justification for ThermXL use

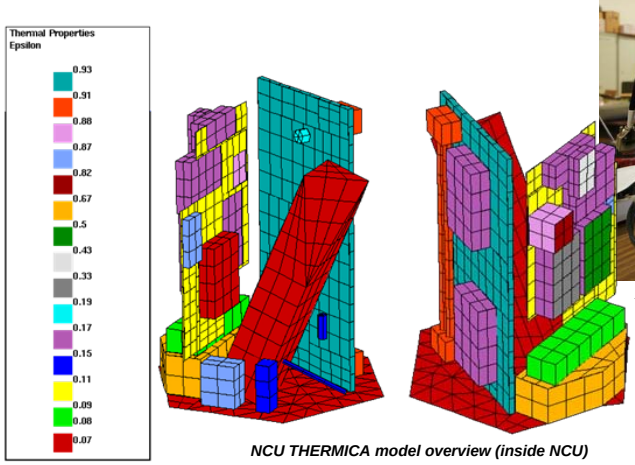
ThermXL: interesting tool for different reasons:

- Low temperature gradient inside gondolas due to good thermal insulation → nodal network is appropriated
- Small thermal model (from ~30 to 60 thermal nodes)
- Short computation time → allows to treat a large amount of cases, results are available in a short time (very useful for predictions before launch)
- Elaboration of a conjugated energy/thermal model is easy

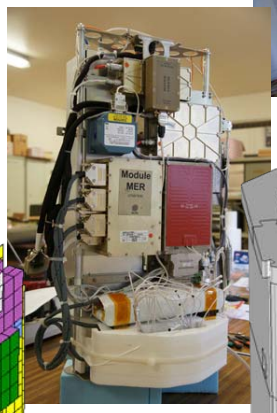
CONCORDIASI (McMurdo 2010): THERMICA model overview

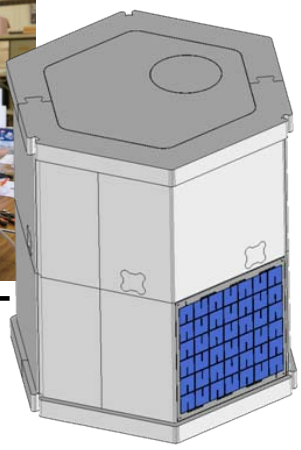
THERMICA model elaborated for scientific payload gondola:

Top view of open gondola



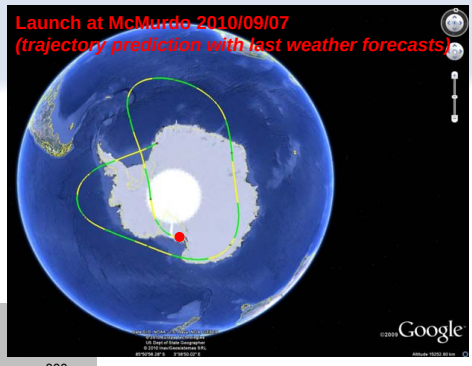
NCU THERMICA model overview (inside NCU)

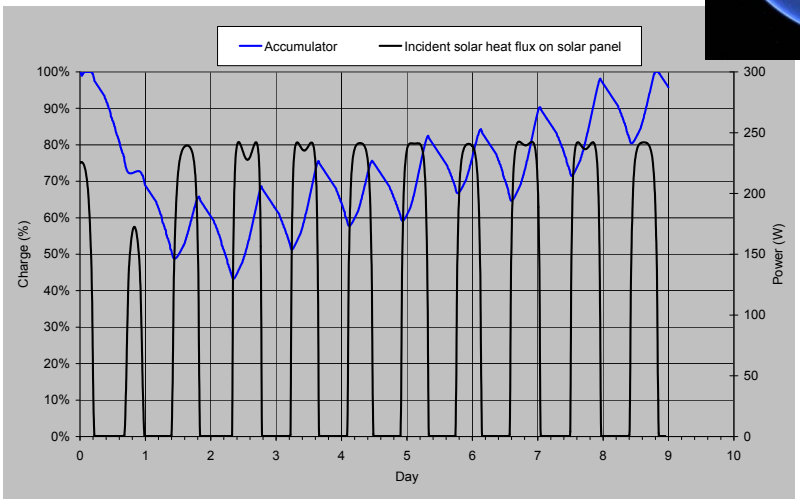




NCU CATIA mock-up

CONCORDIASI (McMurdo 2010): Example of prediction House-keeping gondola





Conservative assumptions have been taken regarding the external environment (low IR ascending flux & albedo)

The first 3 days of flying are the worst because the sunlight is limited, and there is not enough solar power to feed the equipments

It results in a significant decrease of the accumulator charge at the flight beginning

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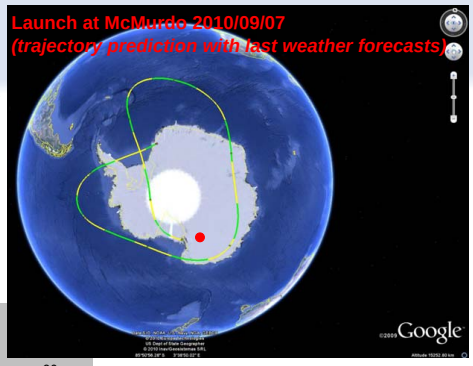
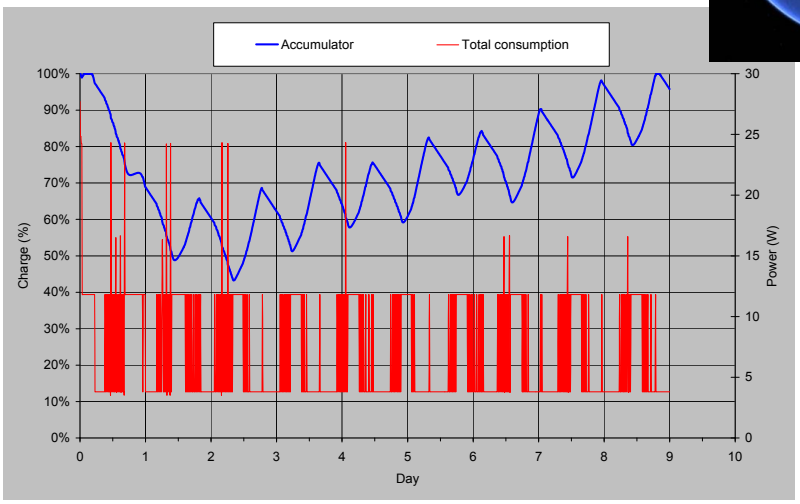
CONCORDIASI (McMurdo 2010): Example of prediction House-keeping gondola





Increase of electrical consumption during the first 3 days of flying, due to a greater need for heating

It contributes to the decrease of the accumulator charge during this period

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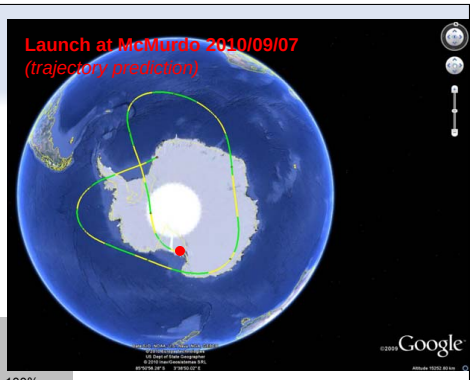
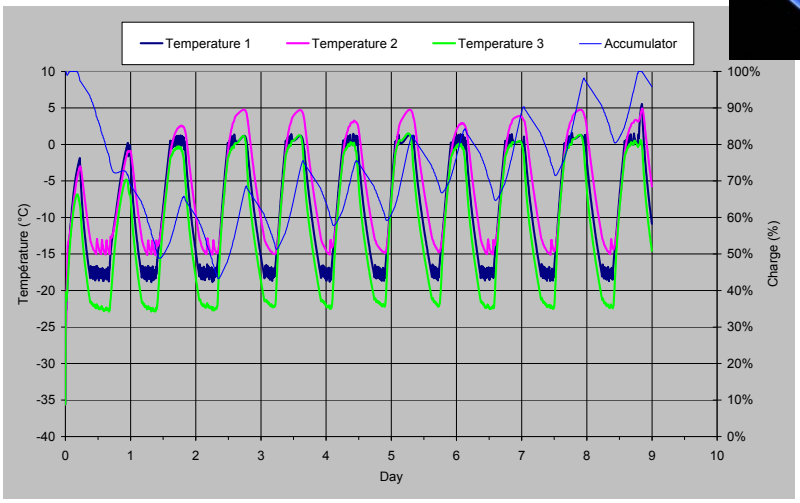
CONCORDIASI (McMurdo 2010): Example of prediction House-keeping gondola

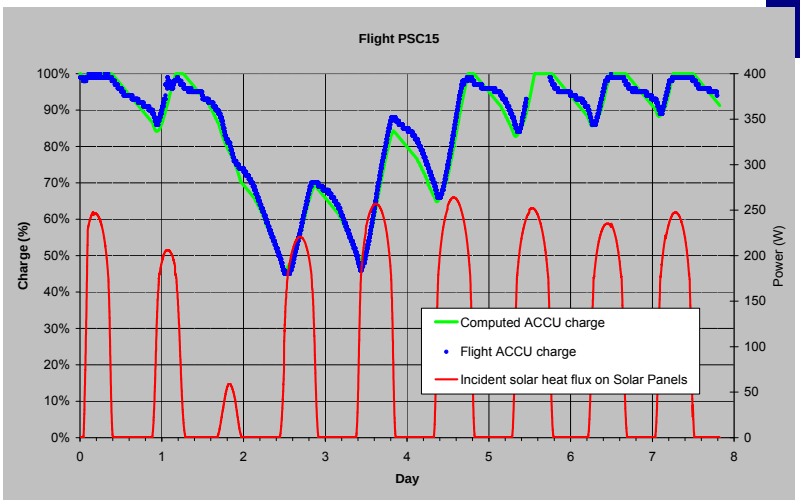




Heating is enough to maintain the equipments at the required temperatures

Computed temperatures between -25°C and +5°C for an overall dissipated power of ~6.9W (heating power of ~3.1W included)

CONCORDIASI (McMurdo 2010): Flight PSC15 House-keeping gondola Restitution of the in-flight behavior



In-flight measurements: air temperature & pressure

Aerostat's trajectory is known

Remaining uncertainties: IR ascending heat fluxes, the Albedo

→ To be consolidated

Nevertheless, encouraging results are obtained

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CONCLUSION

- **CNES offers different kinds of terrestrial aerostats, which are supposed to fly all over the Earth and to be launched at any time and from everywhere**
  - **→ Significant effort must be provided in order to get a better knowledge of external environment (in-flight measurements) & thermal tool to be developed for calculating external boundary conditions**
- **Thermal science is considered in design and verification process, and it concerns both the envelops and gondolas**
  - **Balloon activity is very specific**
  - **Employing the thermal tools used in Space Industry is under investigation (there are other applications than BPS gondolas / McMurdo campaign)**
- **Thermal aspects play an important role in the autonomy of renewable energy gondolas (cf. Concordiasi project / McMurdo campaign)**
  - **ThermXL tool is appropriated to conjugated thermal / energetic analysis or relatively small TCS nodal models &THERMICA is also well appropriated for the computation of radiative exchanges into the gondolas**

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Any questions ?...
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