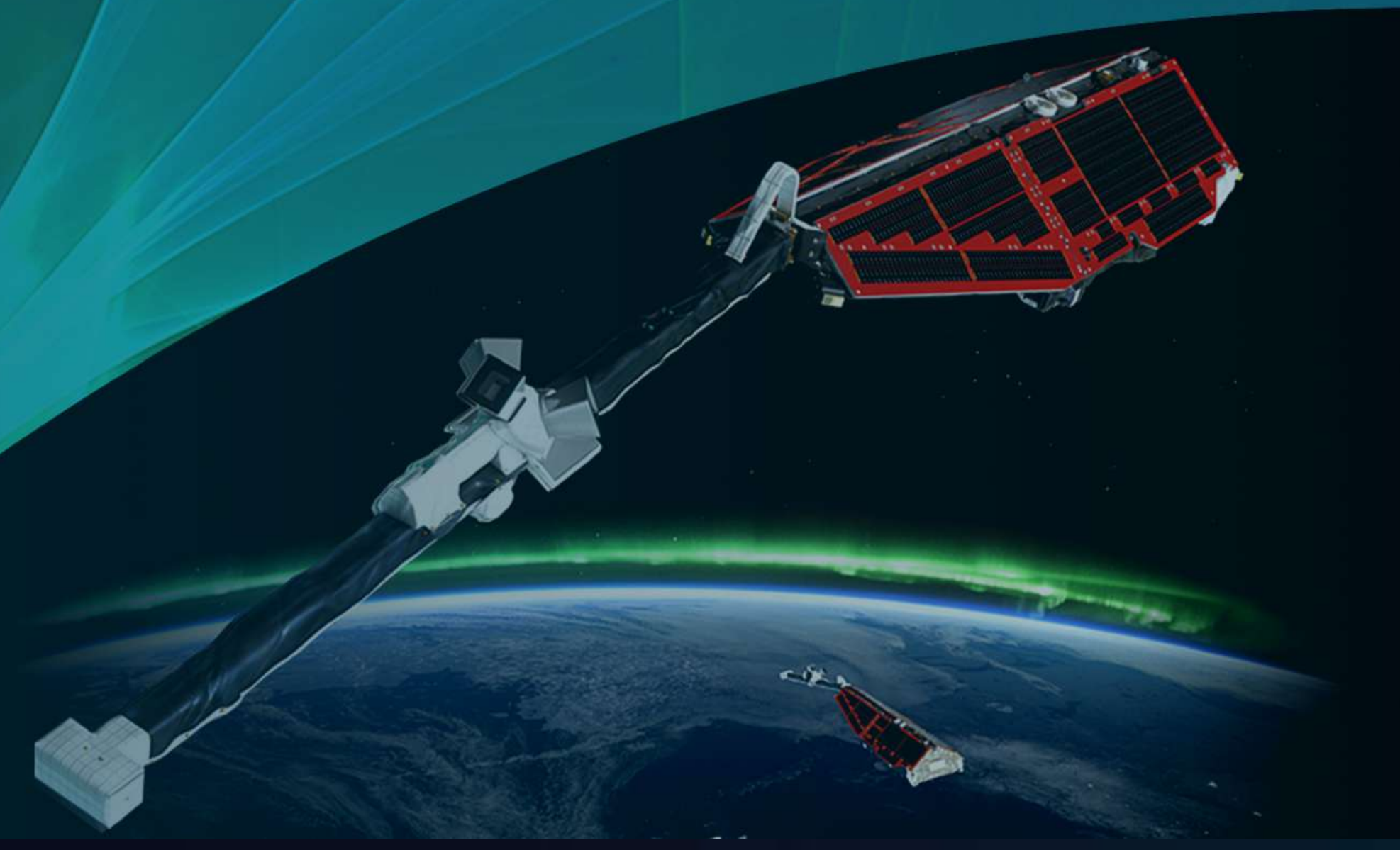
Lessons learned from Swarm radiation pressure modelling for improving GOCE neutral thermosphere crosswind data products



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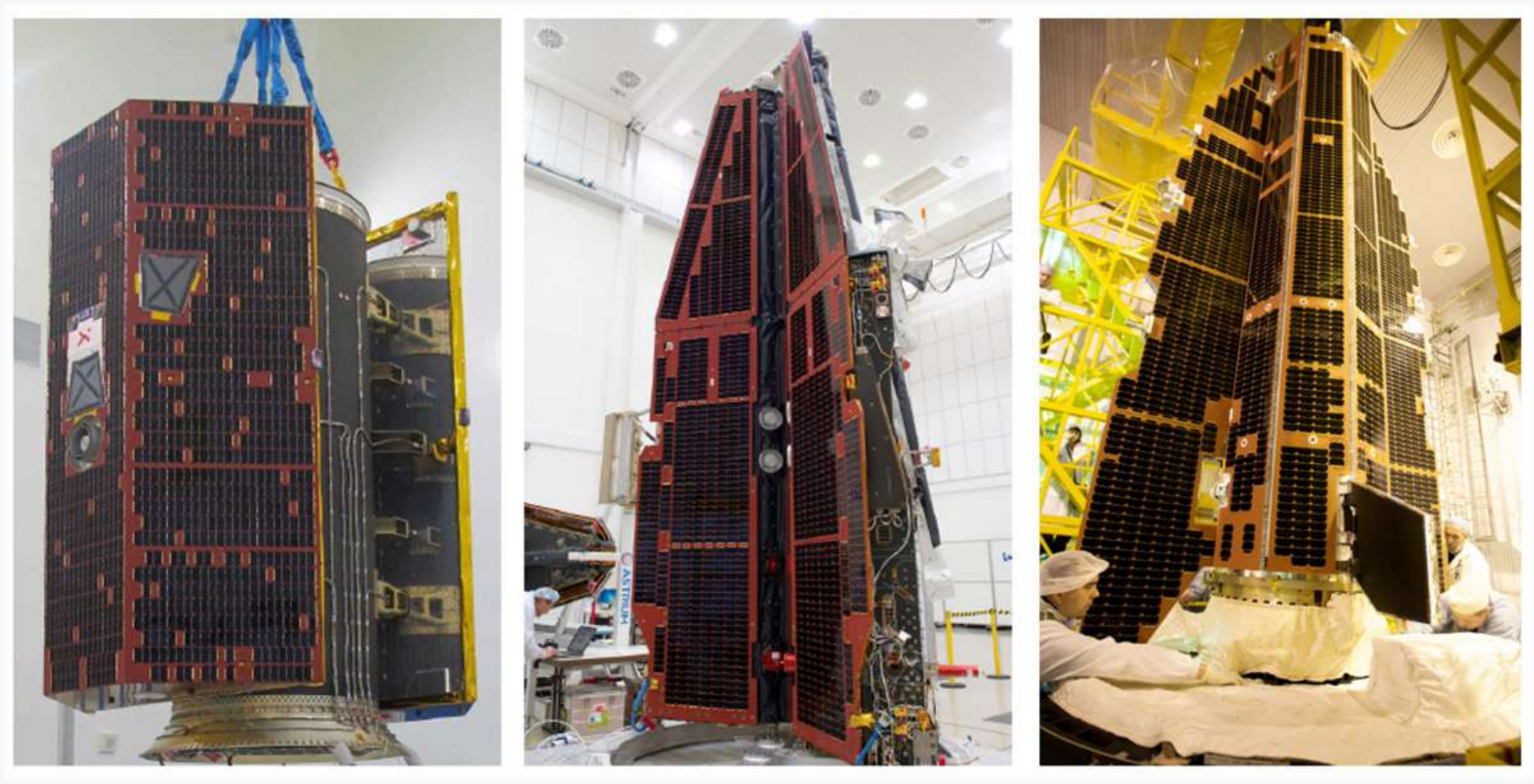
Introduction

The accuracy of wind datasets derived from satellite accelerations is coupled with uncertainties in the aerodynamic and radiation pressure modelling. Previously published GOCE wind datasets did not account for the effect of the thermal emission and utilized a panel geometry for the solar radiation pressure modelling. Deriving a realistic thermal model for GOCE was possible using mission synergies between Swarm and GRACE-FO. All these satellites were equipped with solar panels characterized by the honeycomb structure on which the highly efficient triple-junction Gallium Arsenide (GaAs) solar cells were mounted. However, contrary to GOCE, in the case of Swarm and GRACE-FO the thermistors were placed on top of the panels. Moreover, the two latter missions also provide better documentation on the thermo-optical surface properties. This study shows how to improve the radiation pressure modelling for GOCE and discusses the anticipated impact on the neutral wind observations.



(1) GRACE-FO (2) Swarm (3) GOCE

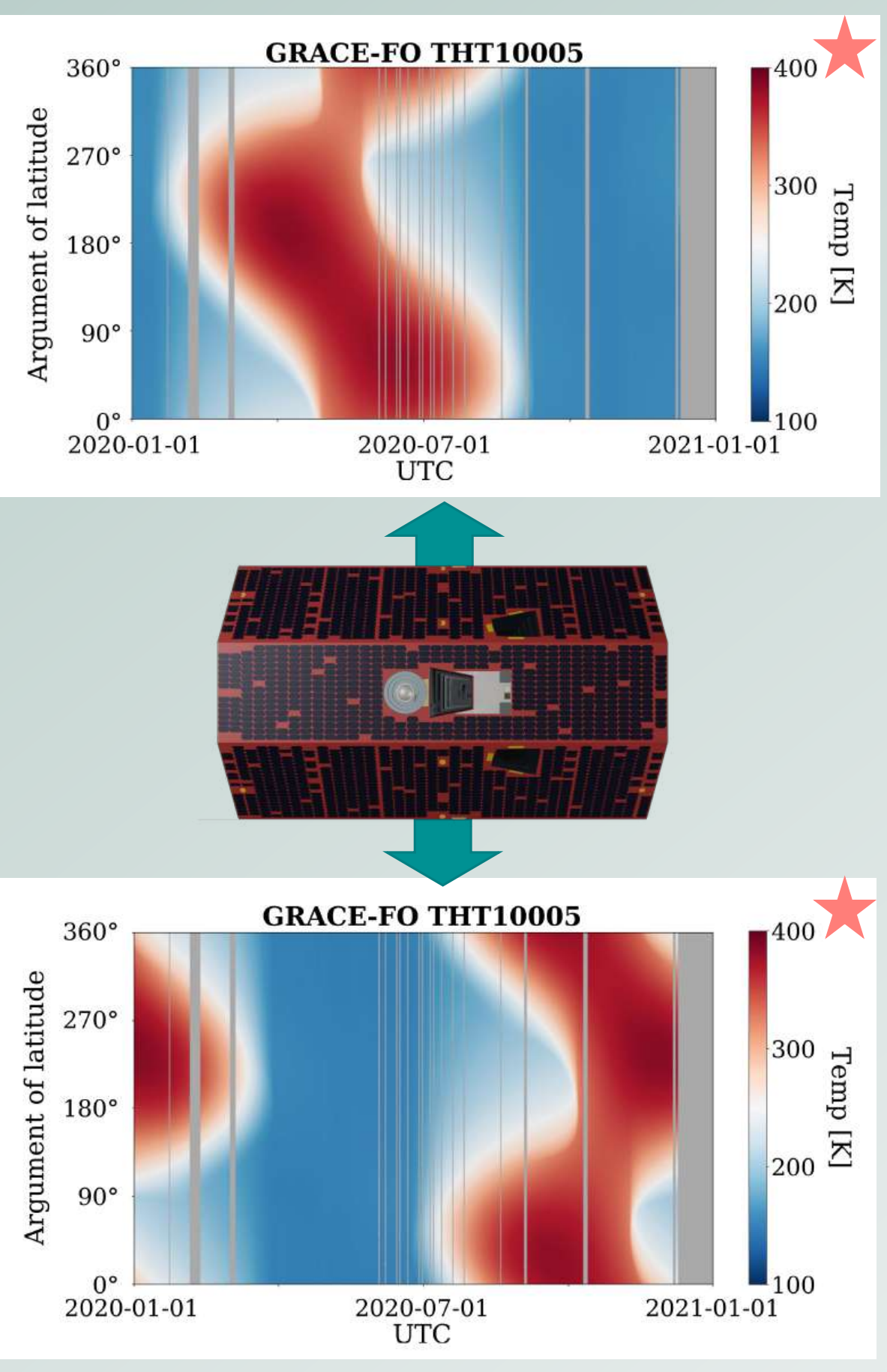
Thermal modelling

The thermal model developed for GRACE-FO, Swarm, and GOCE consists of panels, which heat up by absorbing incoming radiation and cool down by emitting radiation. We took advantage of the in-situ measurements from the GRACE-FO and Swarm thermistors to perform the thermal modelling. For these satellites, each solar array is equipped with two externally located temperature sensors. After investigating the thermal gradient across the surface, we assumed a uniform temperature over the whole panel area. Thermistors' measurements allowed for optimisation of the thermal control model parameters such as (1) the heat capacitance of the panels, (2) the thermal conductance towards the inner satellite, (3) heat conversion to electricity, and (4) the internal heat generation from the electronics, batteries, etc.

GRACE-FO

For this analysis, we used measurements from the GRACE-C satellite (510 km altitude).

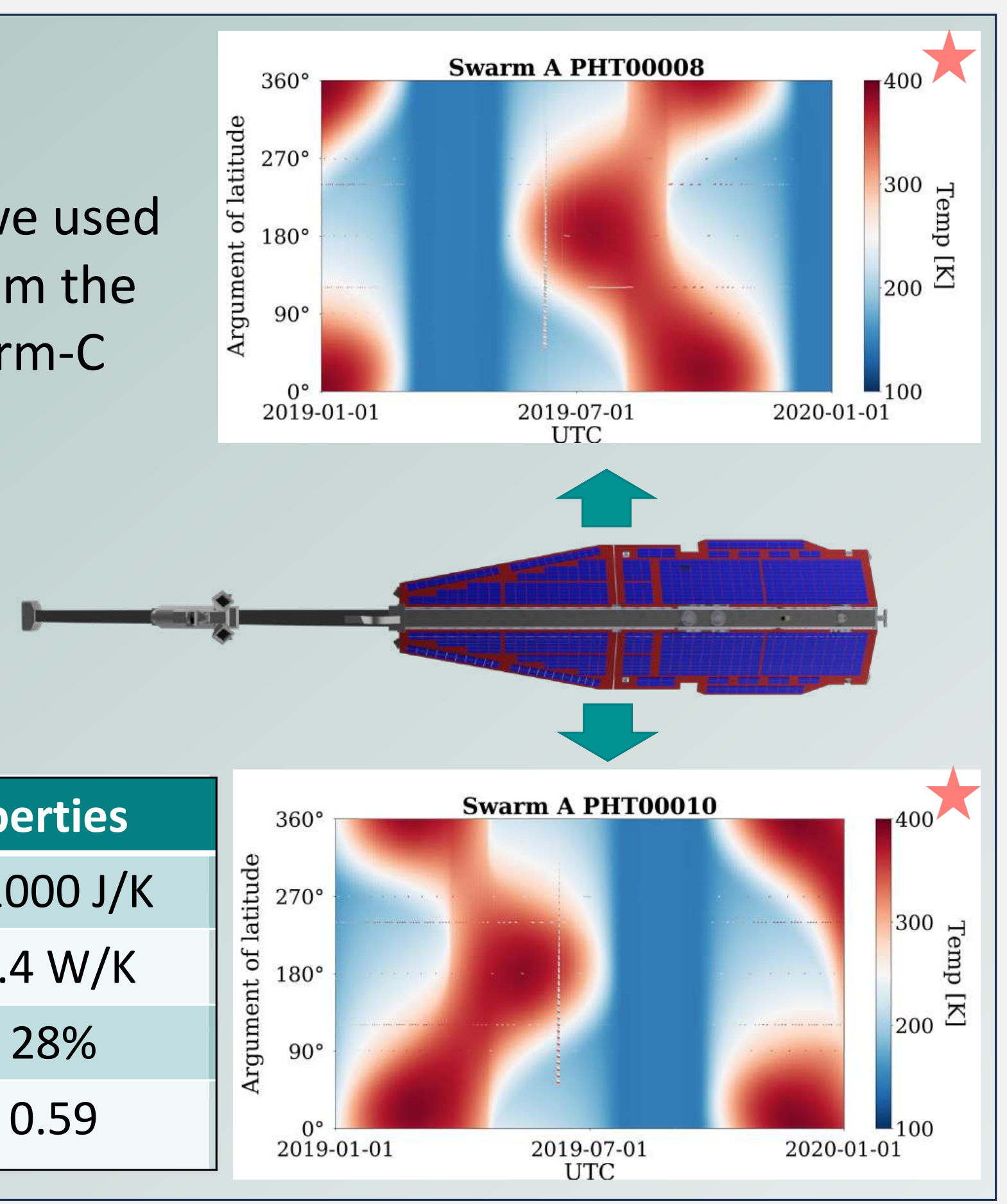
(Data provided by NASA Jet Propulsion Laboratory, JPL)



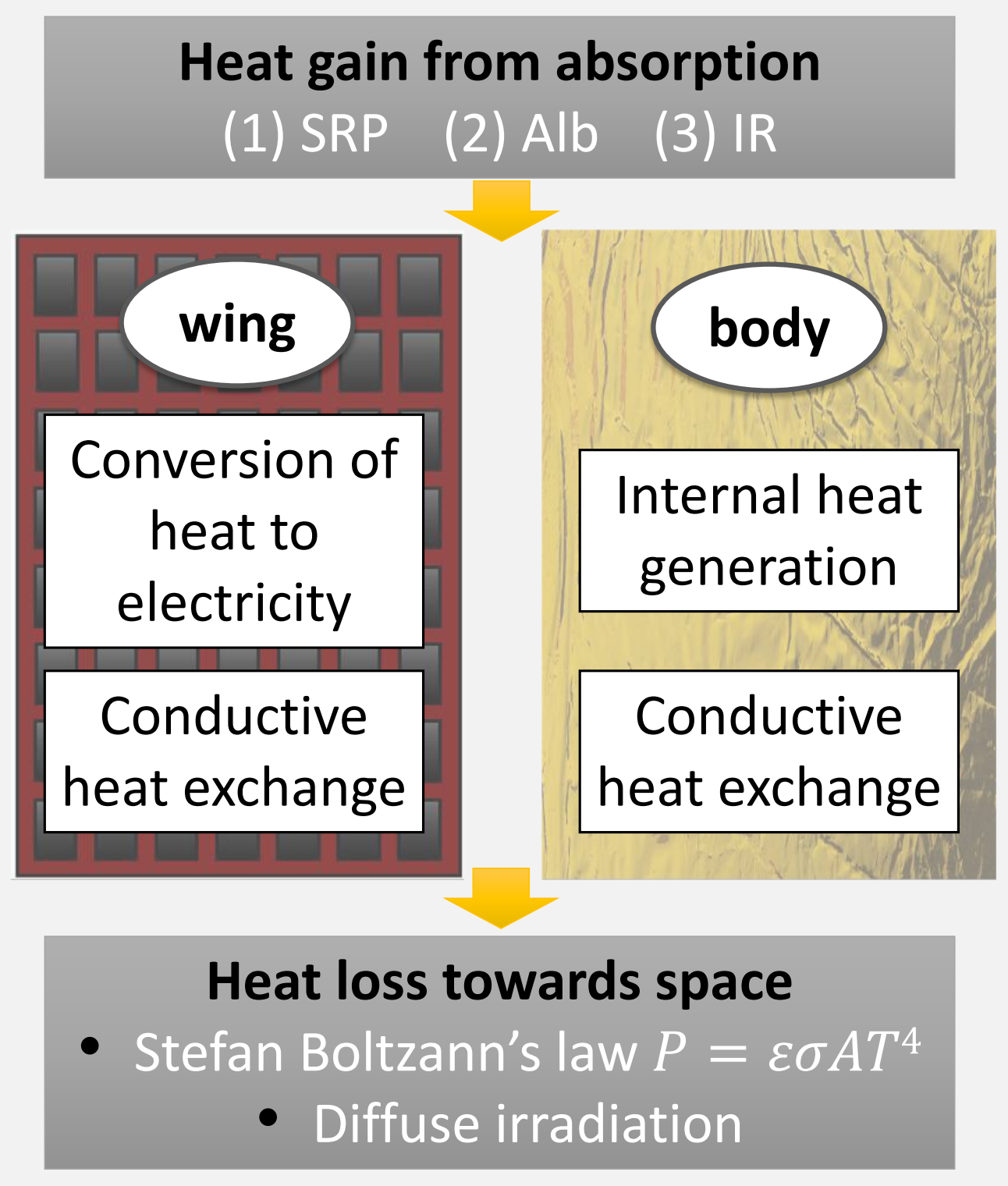
Solar arrays properties	
Capacitance	8200 J/K
Conductivity	0.4 W/K
Efficency	28%
Packing factor	0.66

Swarm

For this analysis, we used measurements from the Swarm-A and Swarm-C satellites (450 km altitude).



Solar arrays properties	
Capacitance	11000 J/K
Conductivity	0.4 W/K
Efficency	28%
Packing factor	0.59



Heat gain from absorption
(1) SRP (2) Alb (3) IR

wing

Conversion of heat to electricity

Conductive heat exchange

body

Internal heat generation

Conductive heat exchange

Heat loss towards space

- Stefan Boltzann's law $P = \varepsilon\sigma A T^4$
- Diffuse irradiation

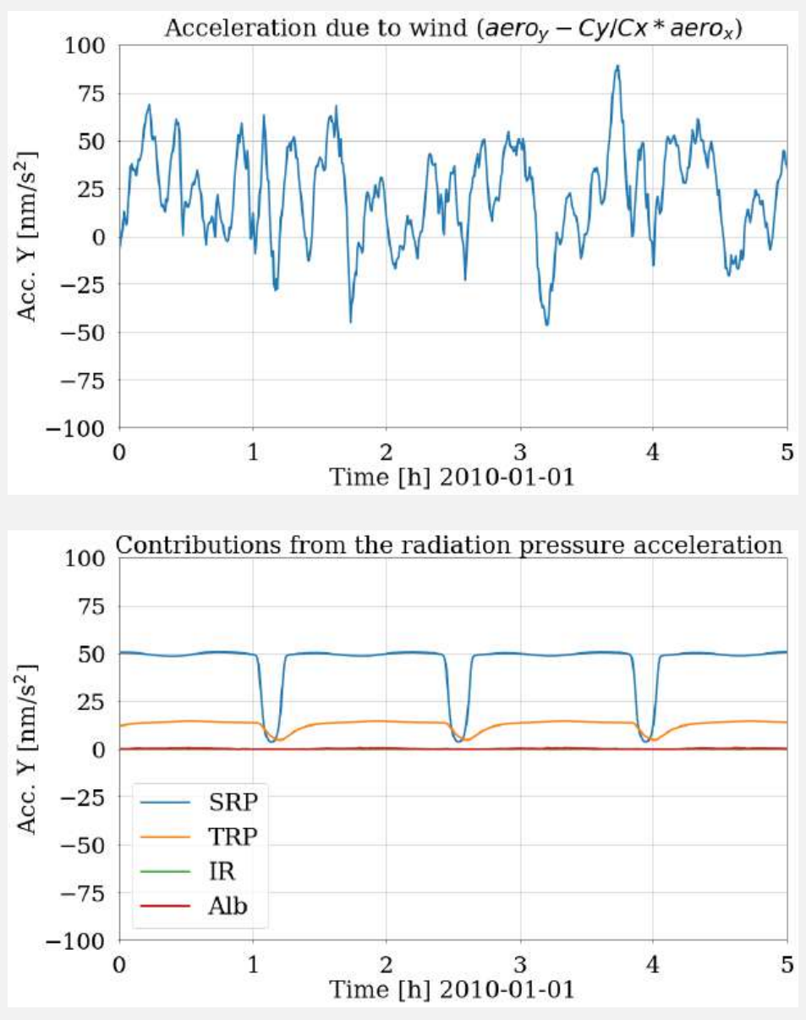


Fig. 1: Cross-track acceleration contributions for GOCE (250 km altitude).

The derived thermal radiation pressure acceleration a_{trp} is a function of the panel temperature T_{wall}, area to mass ratio $\frac{A}{m}$, and emissivity ε. σ is the Stefan-Boltzmann constant, and c is the speed of light.

$$a_{trp} = -\frac{2}{3}\frac{A\sigma}{c\,m}\varepsilon T_{wall}{}^4$$

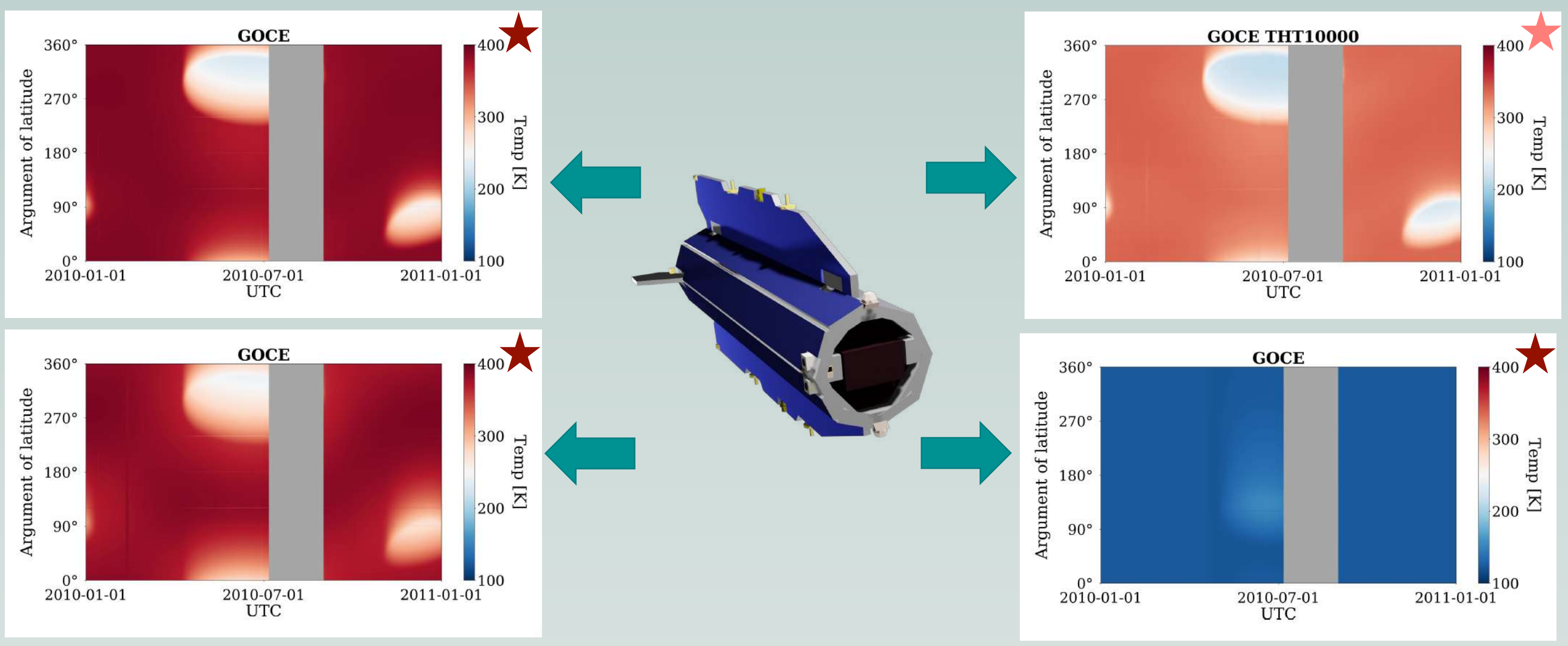
For the wing panels, which do not exchange heat with the satellite body, the acceleration is a function of the front panel temperature T_{front} and the back temperature T_{back} :

$$a_{trp} = -\frac{2}{3}\frac{A\sigma}{c\,m}(\varepsilon_f T_{front}{}^4 - \varepsilon_b T_{back}{}^4)$$

GOCE

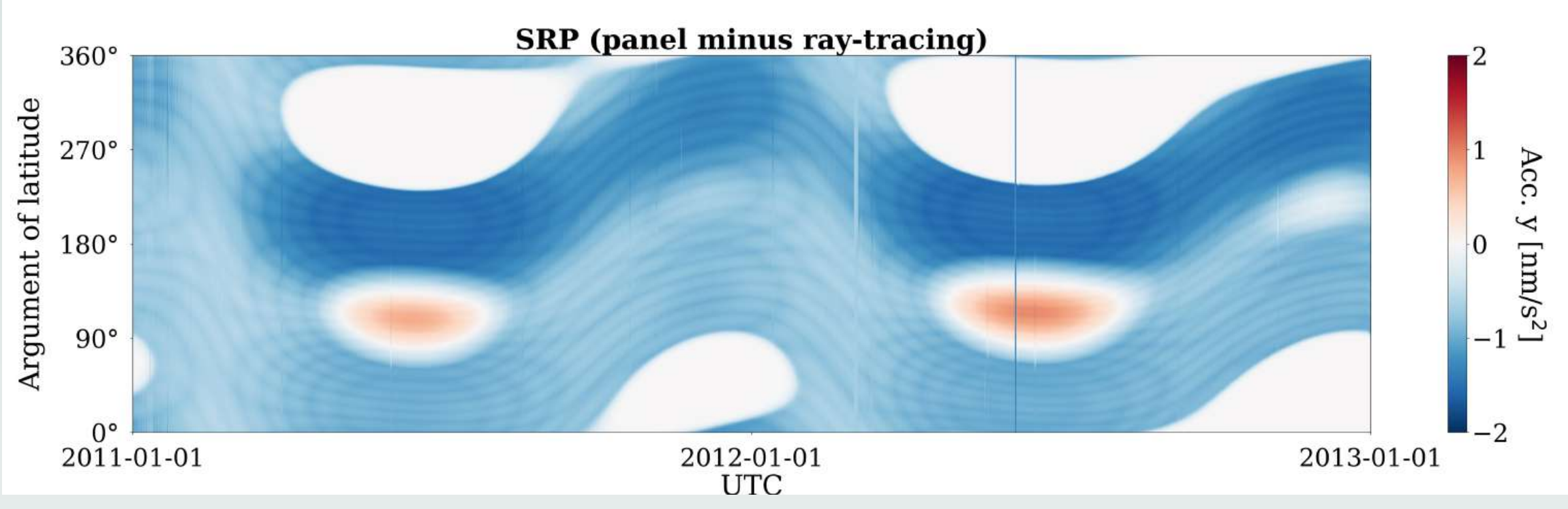
GOCE thermistors were located on the rear side of the panels, making direct use impractical. Considering the **similarities between Swarm, GRACE-FO, and GOCE solar arrays** we could optimise the thermal model for the latter. Additionally, we used the thermistor reading from the back of the GOCE wings to select the value for the heat conductivity of the material (carbon-carbon).

Solar arrays properties		
	Body mounted	**Wing**
Capacitance	5500/6000 J/K	8000 J/K
Conductivity	0.4 W/K	0.25 W/K
Efficency	28%	28%
Packing factor	0.56/0.59	0.72



GOCE ray-tracing

In our approach to solar radiation pressure modelling, we employed the high-fidelity geometry model of GOCE, augmented with parameters describing the thermo-optical surface properties.



Afterwards, we used a ray-tracing technique to derive the force coefficients, accounting for shadowing and multiple reflections.

★ measured temperature
★ modelled temperature

Results

The impact of radiation pressure modelling on the GOCE crosswinds is the most prominent during the low solar activity in 2011 when the ratio of radiation pressure to aerodynamic acceleration was large. Introducing the improved radiation pressure modelling (thermal model and ray-tracing technique) results in a ~20% decrease in crosswind for this period. The improvement is particularly noticeable in the southern hemisphere when the satellite entered the eclipses (i.e. re-radiated the absorbed heat).

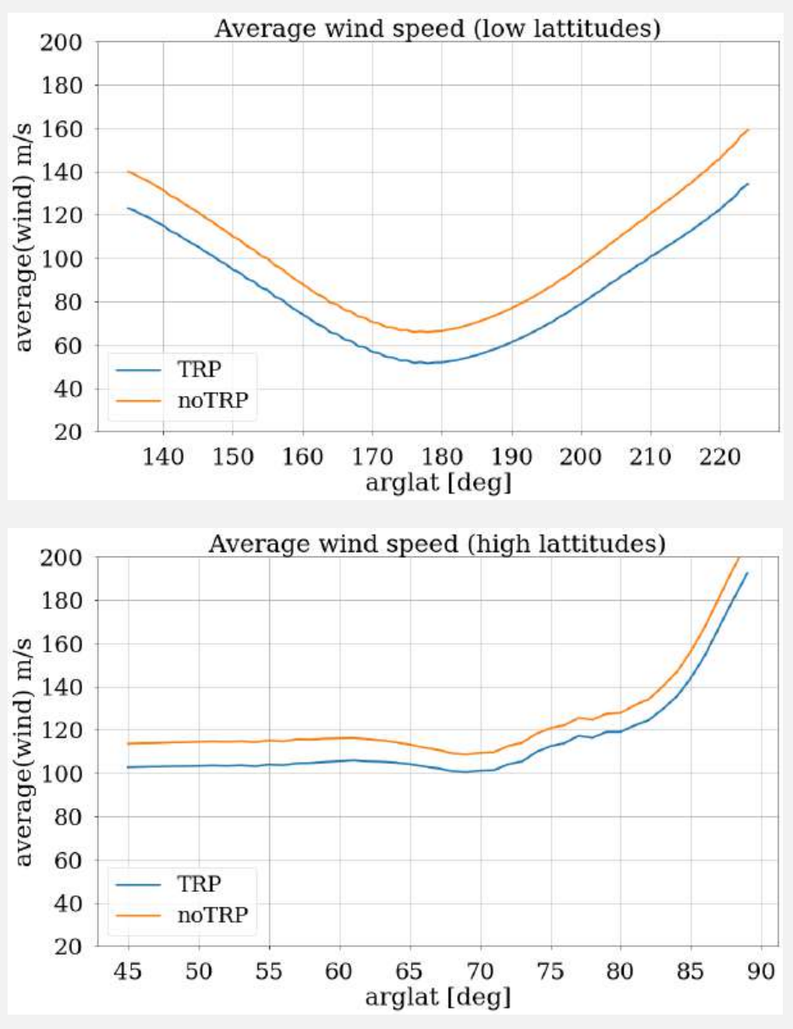
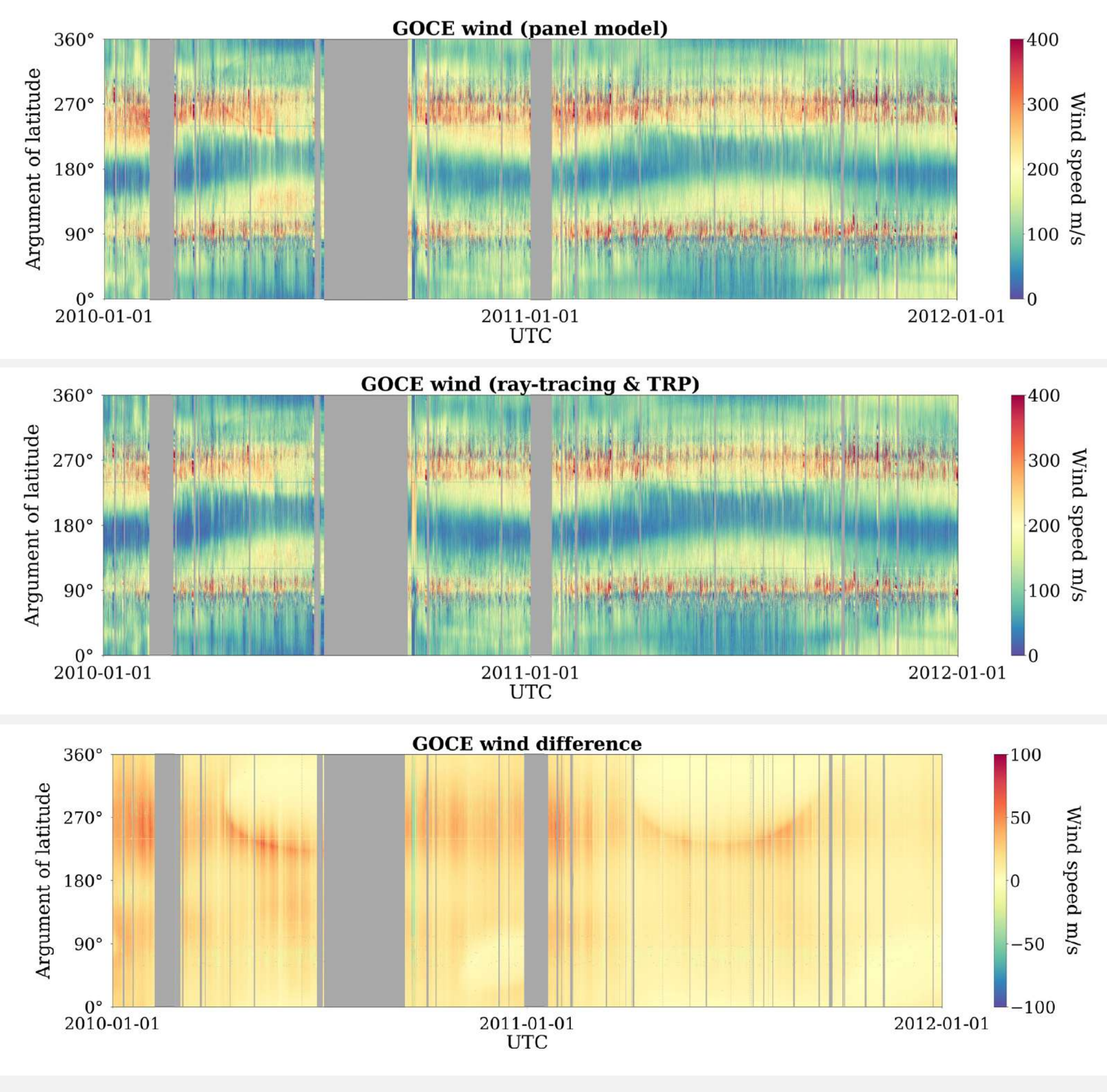


Fig. 2: The magnitude of GOCE crosswinds for high and low latitudes. The data were filtered to select quiet geomagnetic times (K_p<3 and $F_{10.7}$ between 50 and 150 sfu).



→ Introducing the TRP and ray-tracing yields a ~20% decrease in the crosswind signal.

Conclusions and further steps

The thermal behaviour of GOCE can be modelled using the mission synergies between GRACE-FO and Swarm. The improved radiation pressure model results in a ~20% decrease in the crosswind signal, and improves the average wind speed both in low and high latitudes. The performed analysis could help resolve some of the issues with GOCE crosswinds such as low winds in eclipse entrances/exits manifesting as characteristic 'jumps', or overestimated winds near the poles.

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