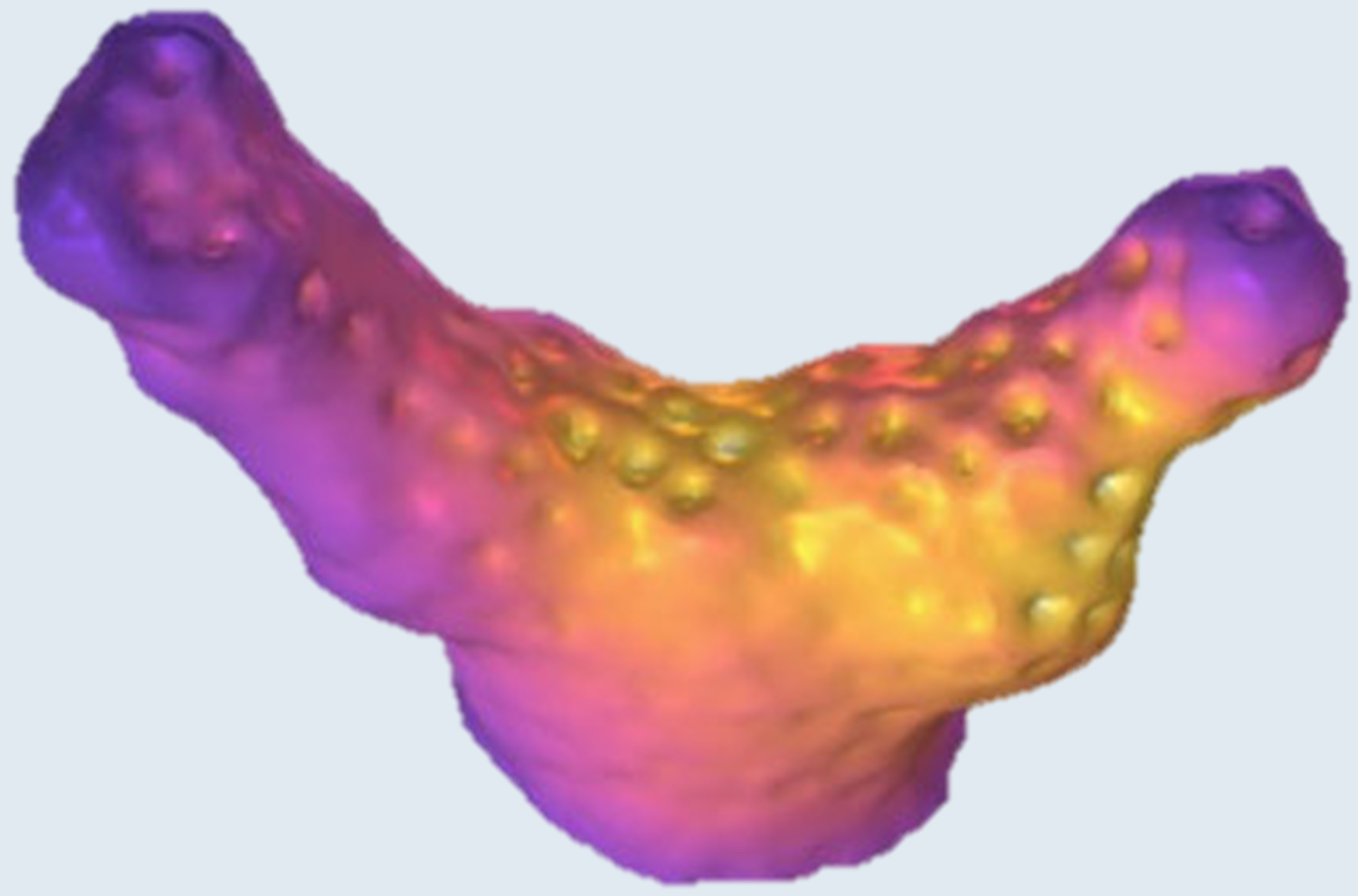

3D Modeling of Light, Flow, Mass and Heat Transfer in Coral Colonies

The model couples a Monte Carlo simulation of light propagation with COMSOL® solving water flow, coral metabolism and heat production to simulate irradiance, hydrodynamics, temperature and oxygen distribution in and around a complex coral geometry

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Introduction

Corals construct a three-dimensional calcium carbonate skeleton, which is the framework for an essential marine ecosystem. Environmental factors related to climate change (such as ocean acidification, gradients of light, deoxygenation and warming), increasingly result in mortality of corals. Hence, it is important to improve the mechanistic understanding of how the photobiology and physiological activity of corals are affected by macroscale colony morphology and microscale variations.

We developed a multiphysics modelling approach to simulate the microscale spatial distribution of light, temperature and dissolved oxygen in and around a coral fragment, all within flow conditions. Several tissue layers with different optical, thermal and diffusional properties were considered on the base skeleton. The complex coral skeleton morphology was determined by 3D scanning techniques (**Fig. 1**).

Model results were compared with microsensor measurements on a coral fragment within an experimental flow chamber (**Fig. 2**).

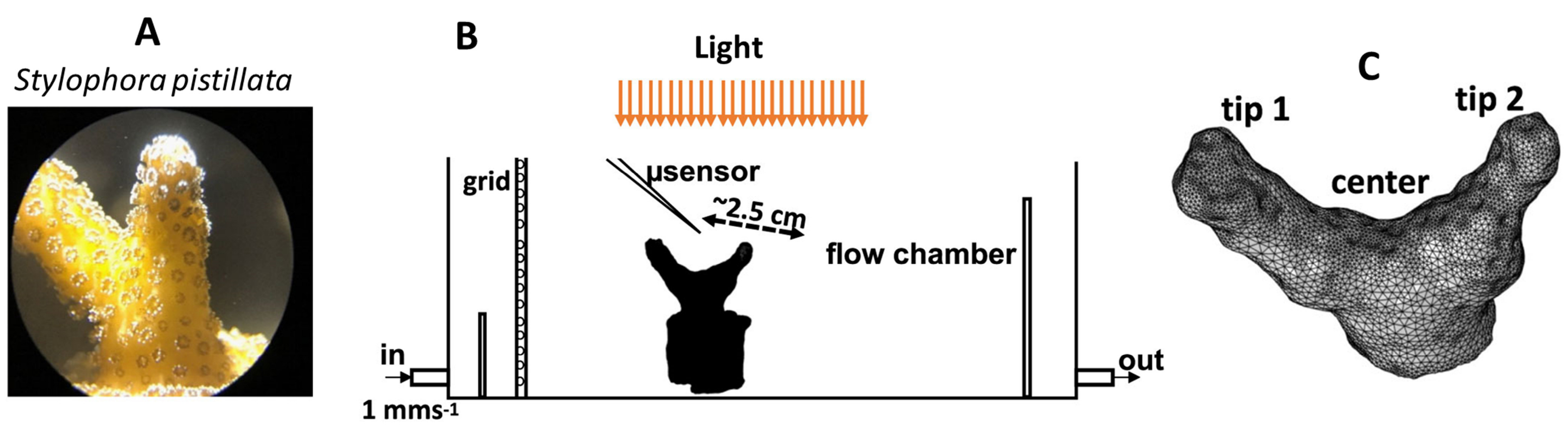


FIGURE 1. (A) Coral fragment; (B) Experimental flow chamber for microsensor measurements; (C) Tetrahedral mesh used for multi-physics simulation, resulting from 3-D scans of the coral.

Methodology

Model geometry: a solid domain - coral skeleton and several stacked coral tissue layers - enclosed by water in the flow chamber.

Physics:

ValoMC

Photon scalar irradiance was calculated by a Monte Carlo approach, considering different optical properties for various tissue layers and skeleton (**Fig. 3A**).

COMSOL

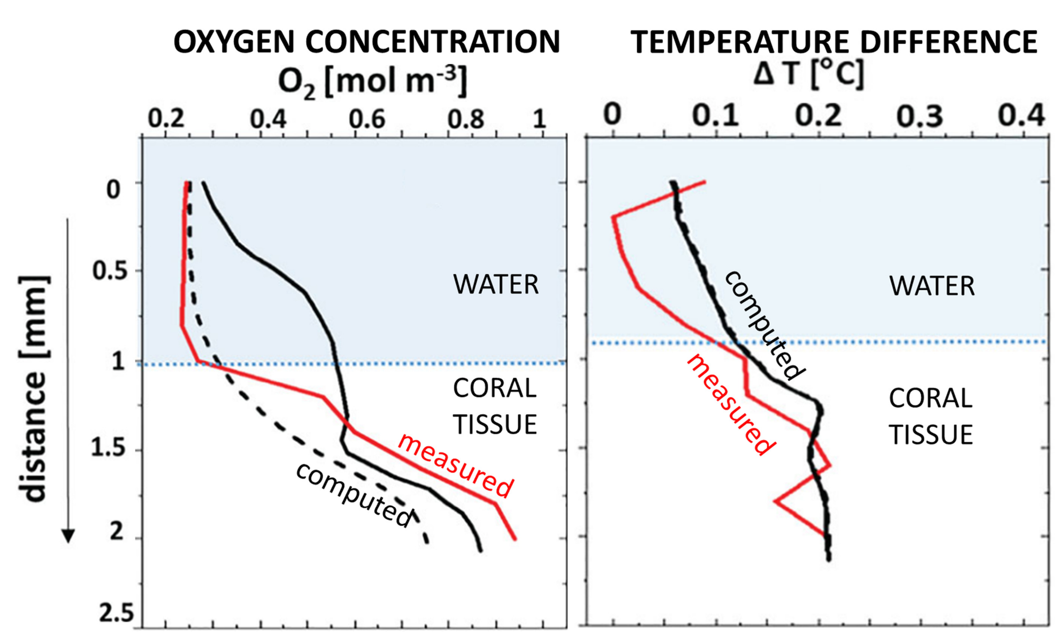
Hydrodynamics around the coral assumed laminar flow, but with ciliary movement on the coral surface (**Fig. 3B**).

Oxygen field resulted from production (function of local irradiance), consumption (function of different tissue metabolisms) and mass transport (diffusion, convection) (**Fig. 3C**).

Temperature resulted from heat source (light absorption) and heat transfer (convection, conduction) (**Fig. 3D**).

Results

FIGURE 2. Oxygen concentration and temperature difference, measured by microsensors across boundary layers and coral tissue (red lines), compared with model simulations (black lines; solid – with cilia, dashed – without cilia).



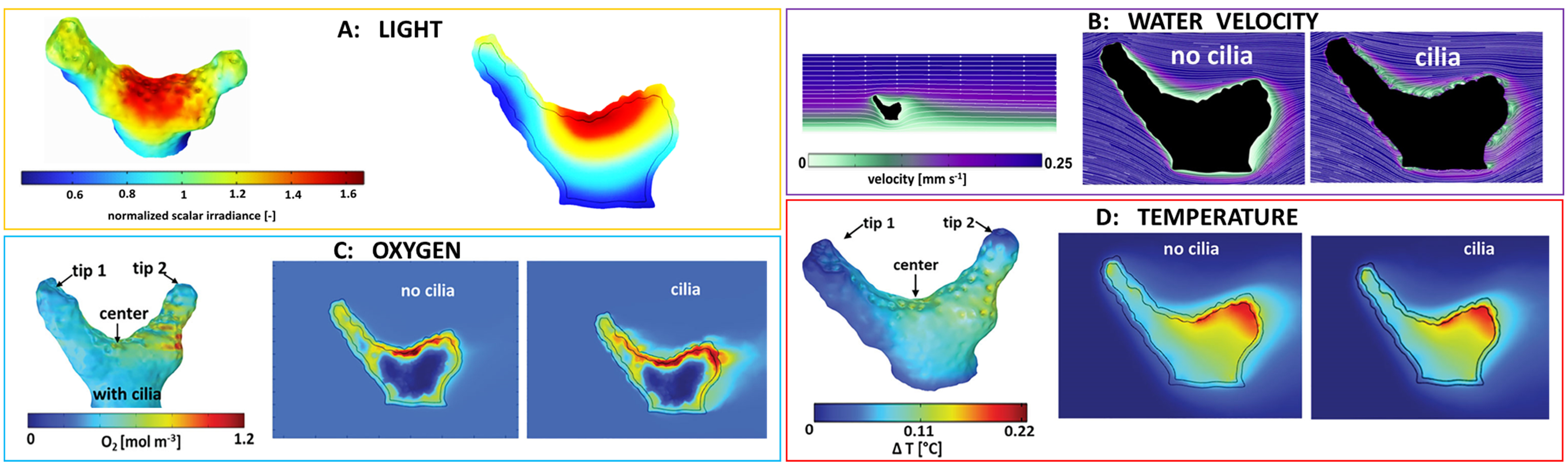


FIGURE 3. Model results. (A) Light fields, as normalized scalar irradiance on the coral surface (left) and transversal slice (right); (B) Water flow field around the coral fragment, with and without ciliary movement on the coral surface; (C) Dissolved oxygen concentration at the coral surface (left) and in transversal slices with (right) and without cilia (center); (D) Temperature difference (local minus bulk water) at the coral surface (left) and in transversal slices with (right) and without (center) cilia.

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Modeling the radiative, thermal and chemical microenvironment of 3D scanned corals
Frontiers Marine Science (Coral Reef Research), 10 (2023) https://doi.org/10.3389/fmars.2023.1160208

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