Potential of a plant gas exchange mechanistic model to predict plant transpiration in Veggie on ISS

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Abstract

Plants are an essential part of long-duration space travel, as they enable food production and contribute to air revitalization through photosynthesis, and water recycling through transpiration. Understanding their growth mechanisms is essential to use them to sustain human life in space. In particular, gas exchange – e.g., CO_2 absorption and water transpiration – are modified in microgravity because of the lack of buoyancy-driven convection, and in the long run, this could result in impaired plant growth. Water absorbed by the plants mainly depends on their size and on environmental conditions (air temperature, humidity and ventilation), but in microgravity watering plants is a delicate operation – too much water results in flooded roots and too little water leads in a few hours to wilted plants. This is regularly experienced in the Veggie system on ISS, which enables small-scale food production in microgravity since 2014. This presentation explores how a mechanistic model of plant gas exchange can help predict plant transpiration in Veggie and thus better predict daily watering. For each plant, inputs on canopy leaf area (acquired with daily photos), air temperature and relative humidity in the plant compartment, as well as airspeed at the top of its canopy enable accurate predictions of transpiration in microgravity. This brings a better understanding of water movement through the plant in microgravity in relation to ventilation and plant size and would result in easier management of plant watering in Veggie. Ultimately, this work could be applied to any space crop production in microgravity and be used for water management and yield predictions. This work was funded by NASA Space Biology through NASA postdoctoral program / USRA.

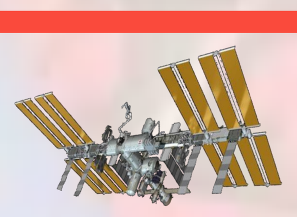
Context and rationale for plant growth in space

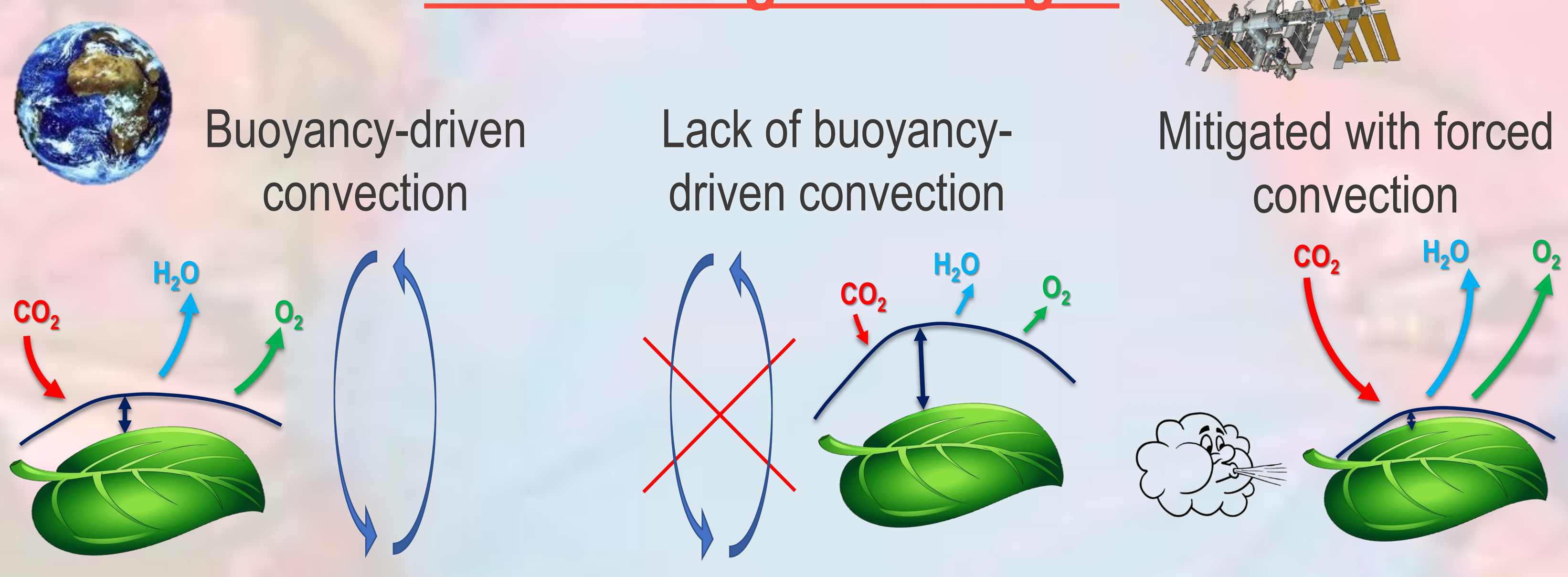
ISS present
Small-scale food production demonstration

Near-term goal
Plants as supplement

Long-term goal
Large-scale production

Gas exchange challenges





Optimal gas-exchange

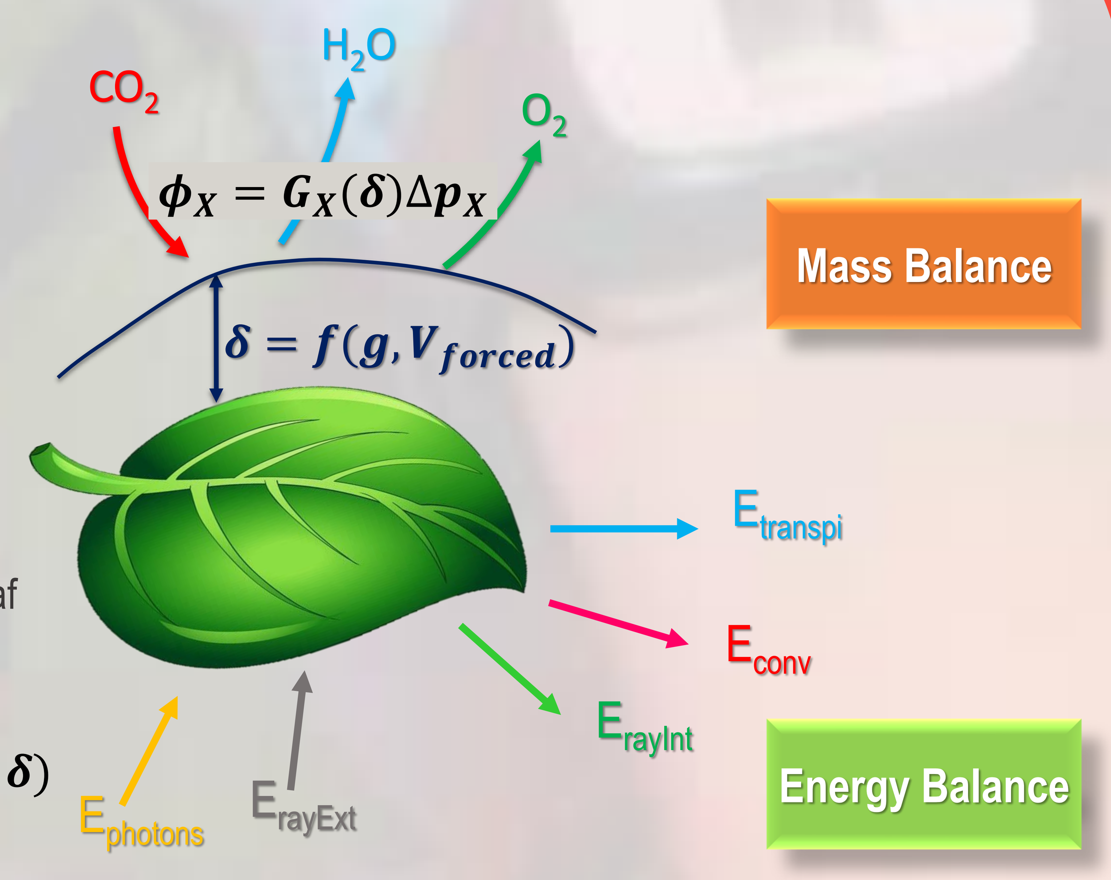
Reduced gas-exchange

Resumed gas-exchange

Mechanistic model[2]

- ϕ_X Mass fluxes
- G_X Conductance
- δ Boundary Layer thickness
- Δp_X Partial Pressure Gradient
- g Gravity
- V_{forced} Forced Convection
- T_{leaf} Leaf temperature
- ϕ_{H_2O} Transpiration rate
- m_{H_2O} Water content in the leaf
- I_0 Incident light intensity

$$T_{leaf} = f(\phi_{H_2O}, m_{H_2O}, I_0, \delta)$$



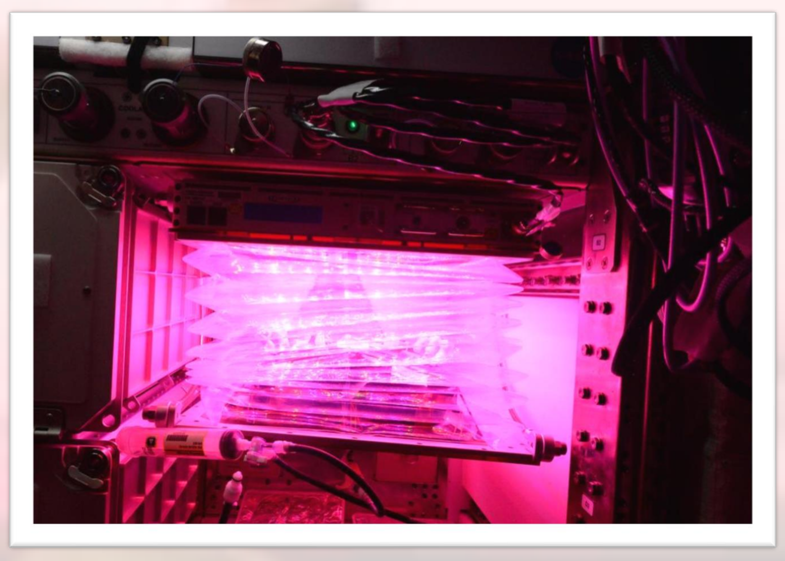
- Single round-leaf assumption
- Gravity: entry parameter
- Outputs: Leaf temperature, Water accumulation, Dry mass accumulation

References

[1] Massa, G. D., Wheeler, R. M., Morrow, R. C., and Levine, H.G., "Growth chambers on the International Space Station for large plants", *Acta Horticulturae*, Vol. 1134, 2016, pp. 215-222.

[2] Poulet, L., Dussap, C.-G., Fontaine, J.-P., "Development of a mechanistic model of leaf surface gas exchange coupling mass and energy balances for life-support systems applications", *Acta Astronautica*, Vol. 175, 2020. pp. 517-530.

Veggie Plant growth system on ISS[1]

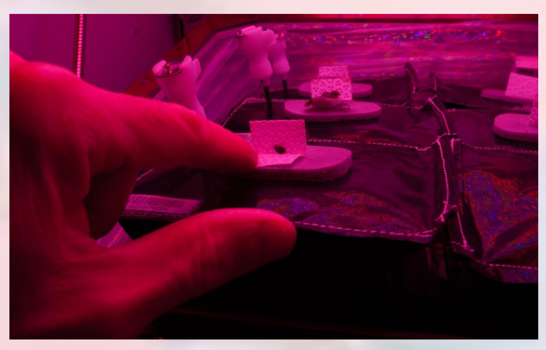


- Growing area: 0.13 m^2
- Height: 5 to 45 cm
- Manual watering
- Build-in fan
- Leafy greens and small fruiting plants
- 6 plants

- Lighting: Red (630 nm), Blue (455 nm), Green (530 nm)
- Environment: ISS cabin air
  - Temperature: 24.8 ºC (day) / 21.7 ºC (night)
  - Relative Humidity: 38.2 % (day) / 44.3 % (night)
  - CO_2: 2798 ppm

Watering and ventilating challenges

Insufficient watering / Excess ventilation



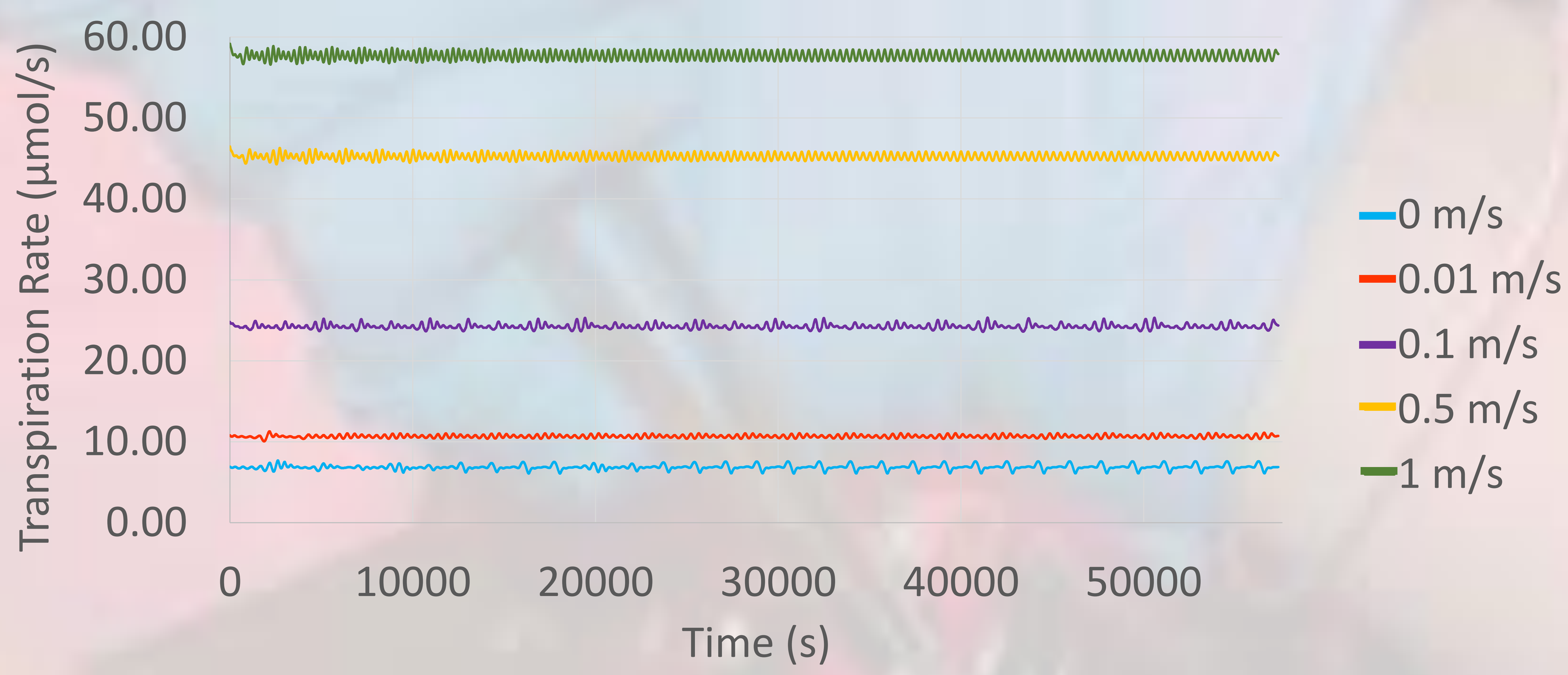
Dried seedling

Excess watering / Lack of ventilation

Stunting and Chlorosis

Guttation and Leaf Curling

Simulation of transpiration rate at 5 different ventilations over a 16-hour photoperiod in Veggie



- Light intensity: 330 µmol/m^2/s with 73% red, 18% blue, 9% green
- Environmental parameters as detailed above; In microgravity: 0.001 m/s^2
- Height of the system: 30 cm; Stomatal conductance: 0.5 mol/m^2/s
- Leaf area of the whole canopy: 880 cm^2

The model can predict a leafy green canopy's transpiration rate over a photoperiod in microgravity for different ventilations and could be used to predict Veggie watering, thus avoiding seedling drying or fungal growth.

Conclusion and perspectives

- Single leaf assumption modeling can be used for a whole plant or canopy for estimation of transpiration rate given environmental parameters.
- These simulations will be compared to experimental data collected in flight and ground experiments.