Temperature Multi-stability

From non-linear radiation terms

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Key Points

The Model

Modifications

Results

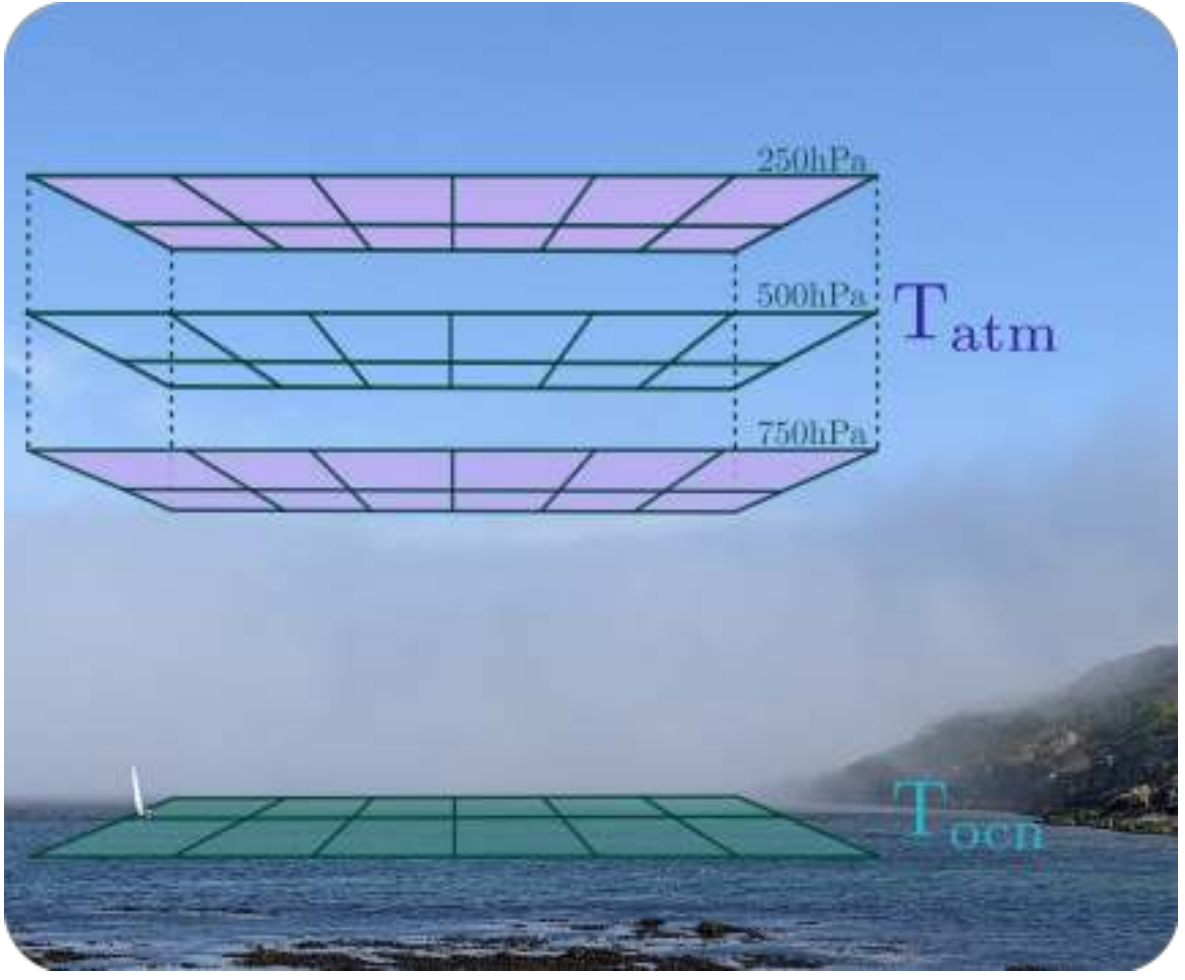
Key Points

The Model

Modifications

Results

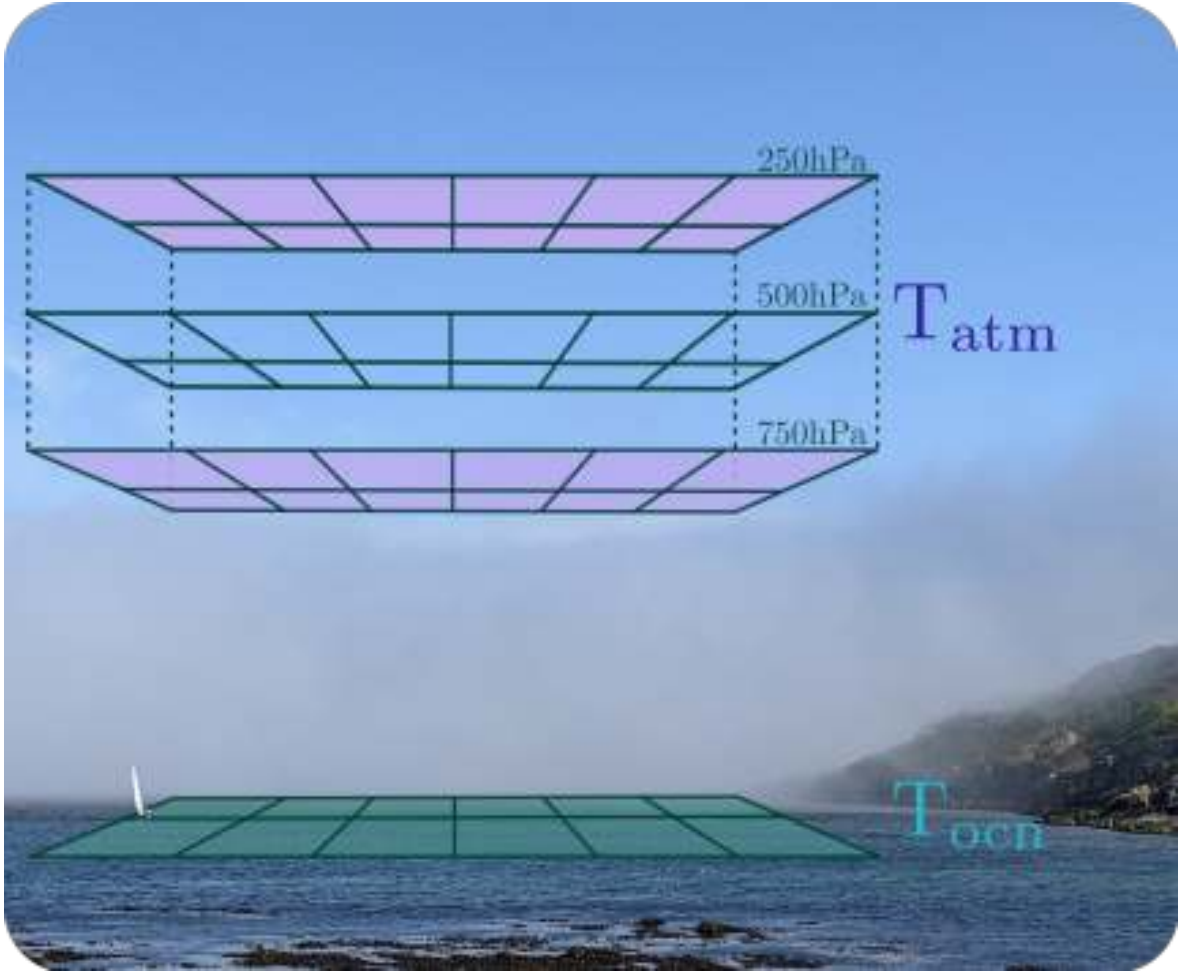
QGS Model



QGS Model

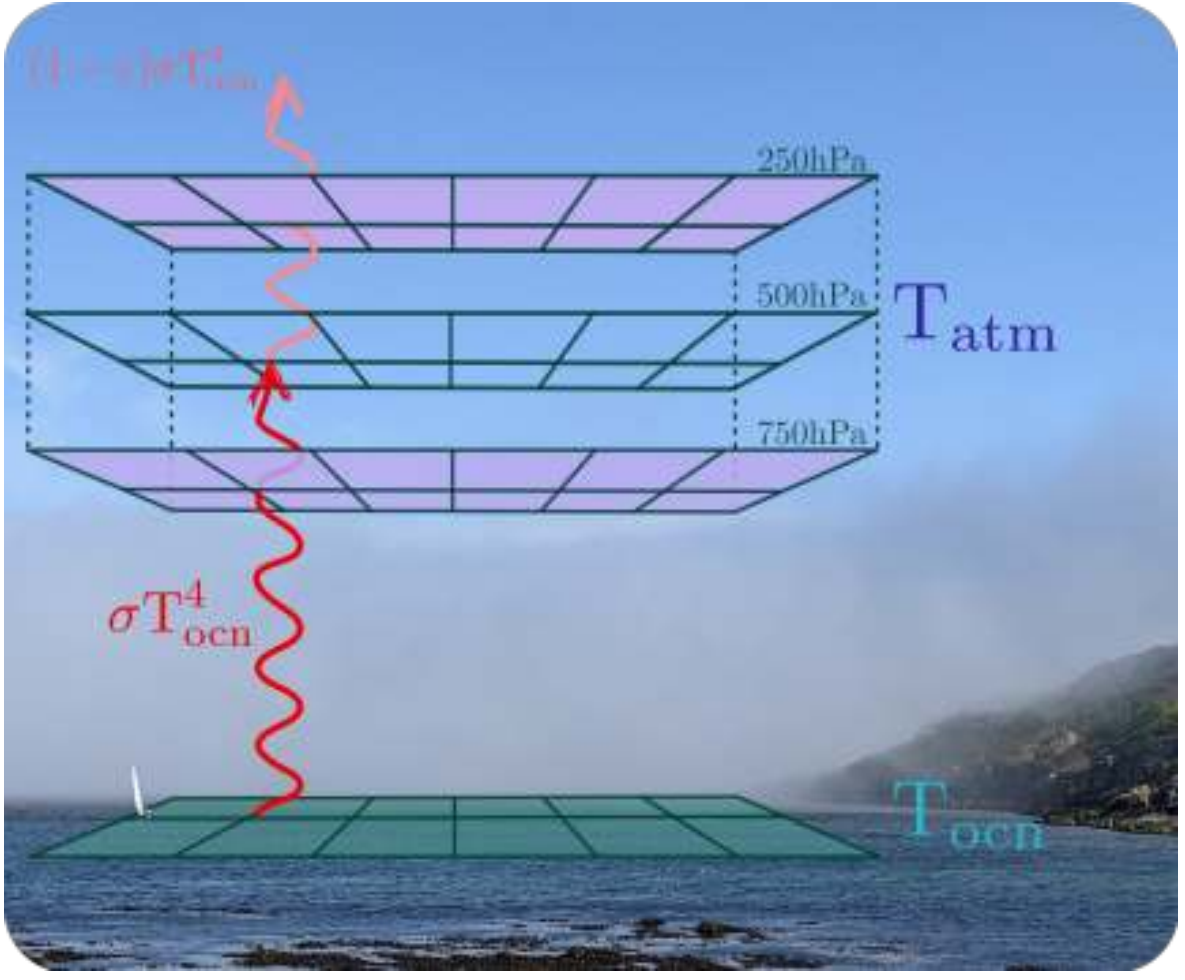
Stefan Boltzmann Law

QGS Model



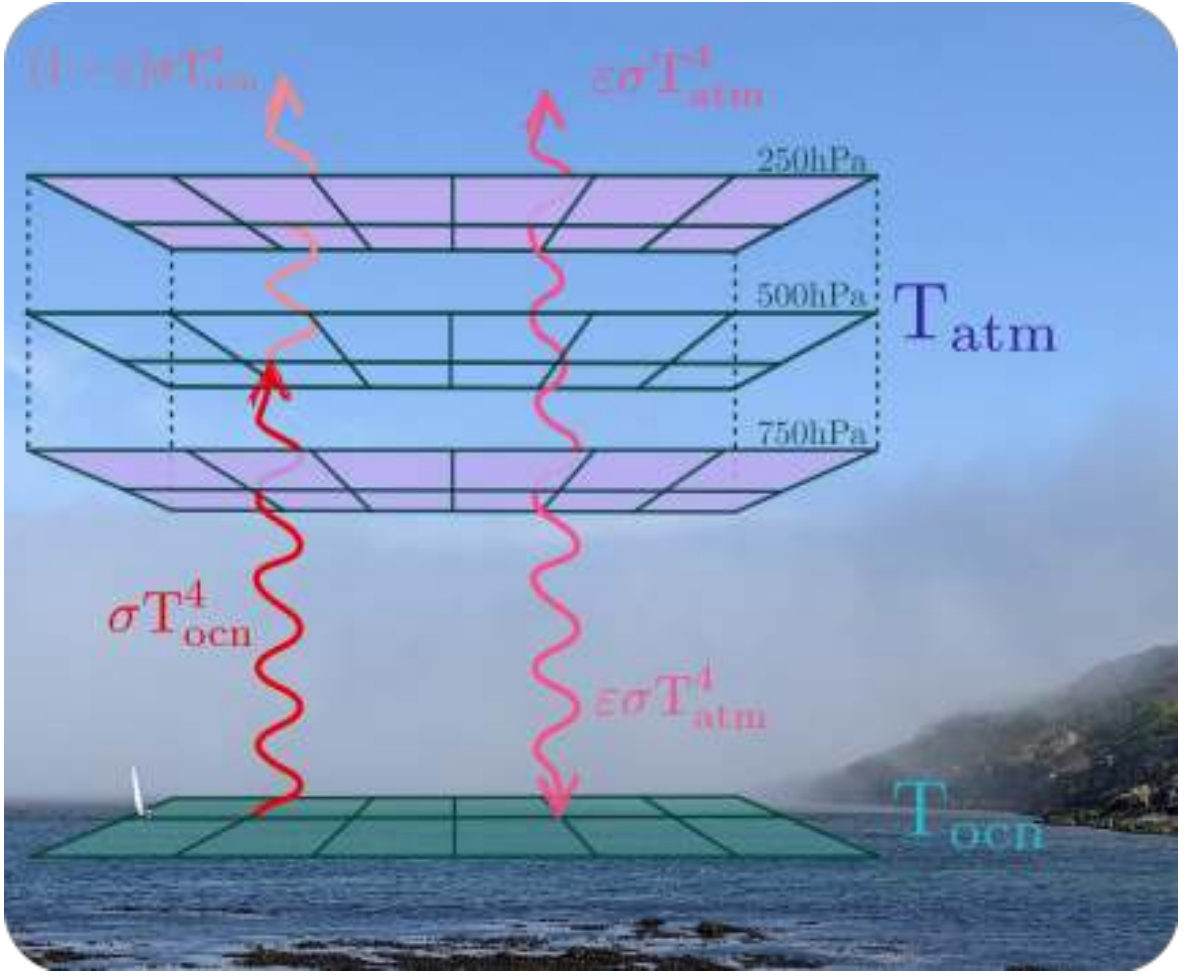
QGS Model

Radiation



QGS Model

Radiation



QGS Model

Temperature Equation

$$\gamma_o\left(\frac{\partial \mathrm{T}_o}{\partial t} + J(\psi_o, \mathrm{T}_o)\right) = -\lambda(\mathrm{T}_o - \mathrm{T}_\mathrm{a}) - \sigma_B \mathrm{T}_o^4 + \varepsilon\sigma_B \mathrm{T}_\mathrm{a}^4 + R_o$$

QGS Model

Temperature Equation

$$\gamma_o\left(\frac{\partial \mathrm{T}_o}{\partial t} + J(\psi_o, \mathrm{T}_o)\right) = -\lambda(\mathrm{T}_o - \mathrm{T_a}) - \sigma_B \mathrm{T}_o^4 + \varepsilon\sigma_B \mathrm{T_a}^4 + R_o$$

QGS Model

Temperature Equation

$$\gamma_o\left(\frac{\partial \mathrm{T}_o}{\partial t} + J(\psi_o, \mathrm{T}_o)\right) = -\lambda(\mathrm{T}_o - \mathrm{T_a}) - \sigma_B \mathrm{T}_o^4 + \varepsilon\sigma_B \mathrm{T_a}^4 + R_o$$

QGS Model

Linearisation

$$-\sigma_B \mathrm{T}_o^4 + \varepsilon \sigma_B \mathrm{T}_\mathrm{a}^4$$

QGS Model

Linearisation

$$\mathrm{T}_o = \mathrm{T}_{o,0} + \delta\mathrm{T}_o(t,x,y)$$

$$-\sigma_B \mathrm{T}_o^4 + \varepsilon\sigma_B \mathrm{T}_\mathrm{a}^4$$

QGS Model

Linearisation

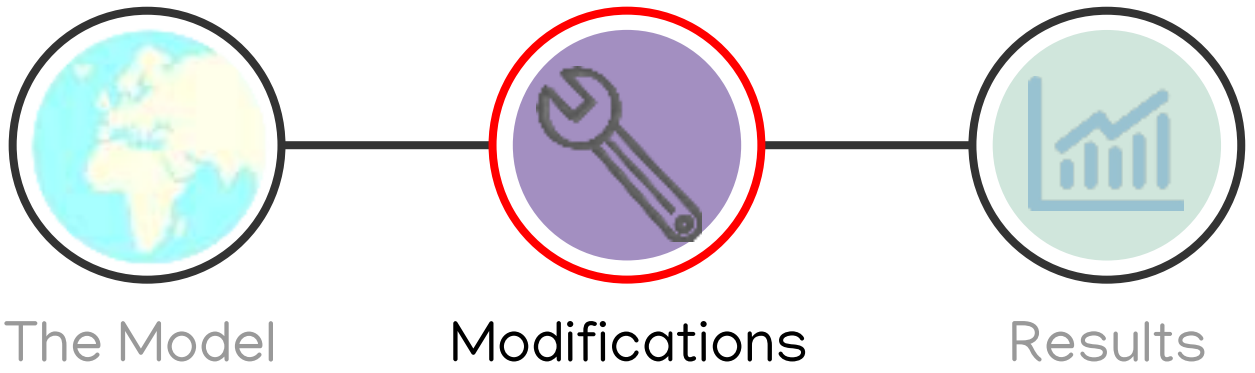
$$\mathrm{T}_o = \mathrm{T}_{o,0} + \delta\mathrm{T}_o(t,x,y)$$

$$-\sigma_B \mathrm{T}_o^4 + \varepsilon\sigma_B \mathrm{T}_\mathrm{a}^4$$

$O(\delta\mathrm{T}_o)$

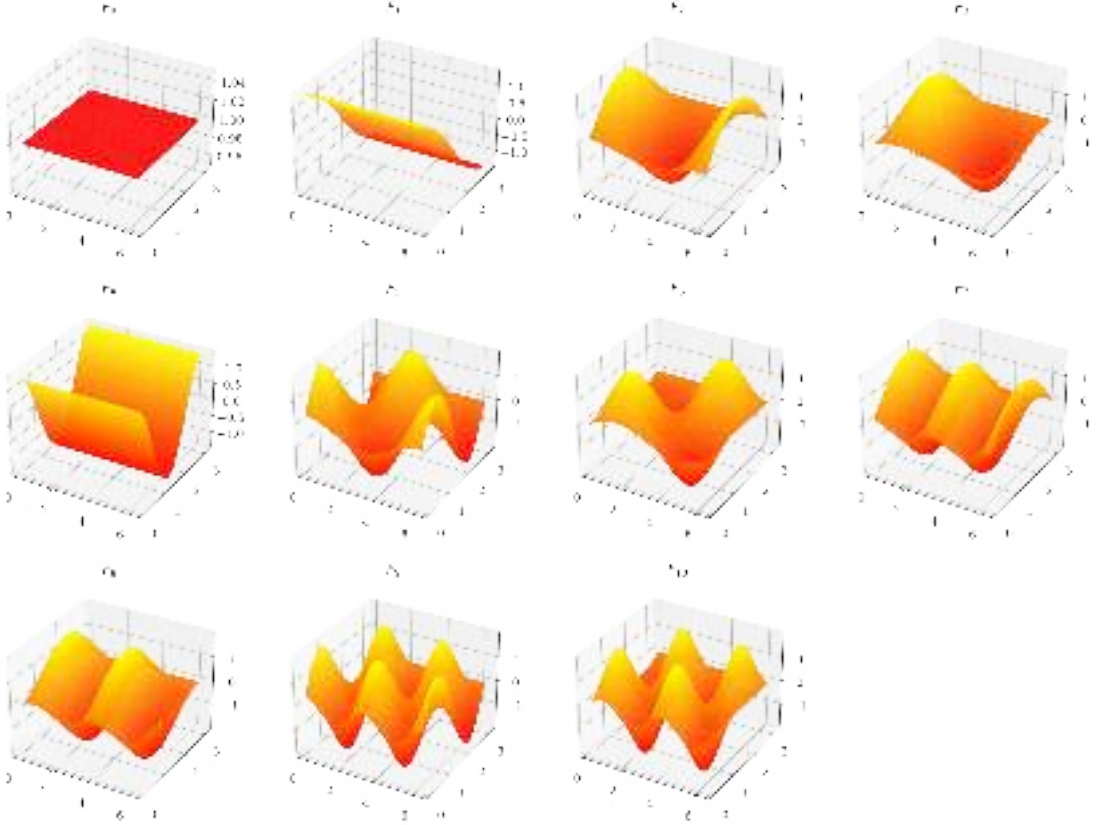
$$-4\sigma_B \mathrm{T}_{o,0}^3 \delta\mathrm{T}_o + 4\varepsilon\sigma_B \mathrm{T}_{\mathrm{a},0}^3 \delta\mathrm{T}_\mathrm{a}$$

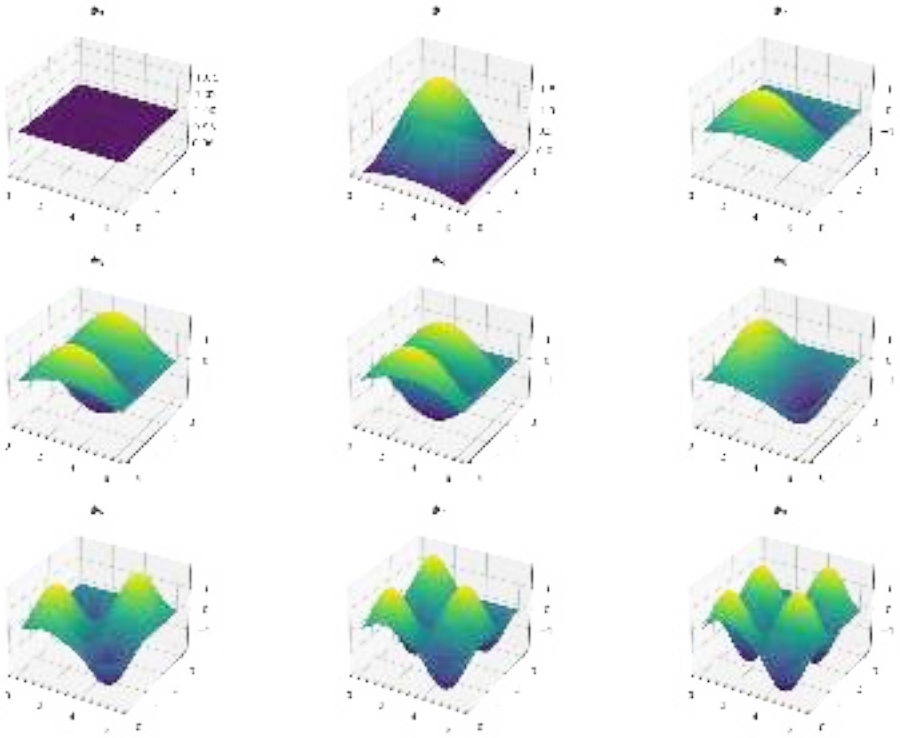
Key Points



Modifications

New Modes





Modifications

Dynamic Equilibrium

$$\mathrm{T}_o = \mathrm{T}_{o,0}(t) + \delta\mathrm{T}_o(t,x,y)$$

$$-\sigma_B \mathrm{T}_o^4 + \varepsilon\sigma_B \mathrm{T}_{\mathrm{a}}^4$$

Modifications

Dynamic Equilibrium

$$\mathrm{T}_o = \mathrm{T}_{o,0}(t) + \delta\mathrm{T}_o(t,x,y)$$

$$-\sigma_B \mathrm{T}_o^4 + \varepsilon\sigma_B \mathrm{T}_\mathrm{a}^4$$

$$O(\delta\mathrm{T}_o)$$

Modifications

Dynamic Equilibrium

$$\mathrm{T}_o = \boxed{\mathrm{T}_{o,0}(t)} + \delta\mathrm{T}_o(t,x,y)$$

$$-\sigma_B \mathrm{T}_o^4 + \varepsilon\sigma_B \mathrm{T}_{\mathrm{a}}^4$$

$$O(\delta\mathrm{T}_o)$$

$$-\sigma_B \mathrm{T}_{o,0}^4 + \varepsilon\sigma_B \mathrm{T}_{\mathrm{a},0}^4 + f(\delta\mathrm{T}_o) + g(\delta\mathrm{T}_{\mathrm{a}})$$

Modifications

Non-Linear Equation

$$\mathrm{T}_o(t,x,y)$$

$$-\sigma_B \mathrm{T}_o^4 + \varepsilon \sigma_B \mathrm{T}_{\mathrm{a}}^4$$

Modifications

Non-Linear Equation

$$\mathrm{T}_o(t, x, y)$$

$$-\sigma_B \mathrm{T}_o^4 + \varepsilon \sigma_B \mathrm{T}_\mathrm{a}^4$$

Problem:

5–6x run time

Modifications

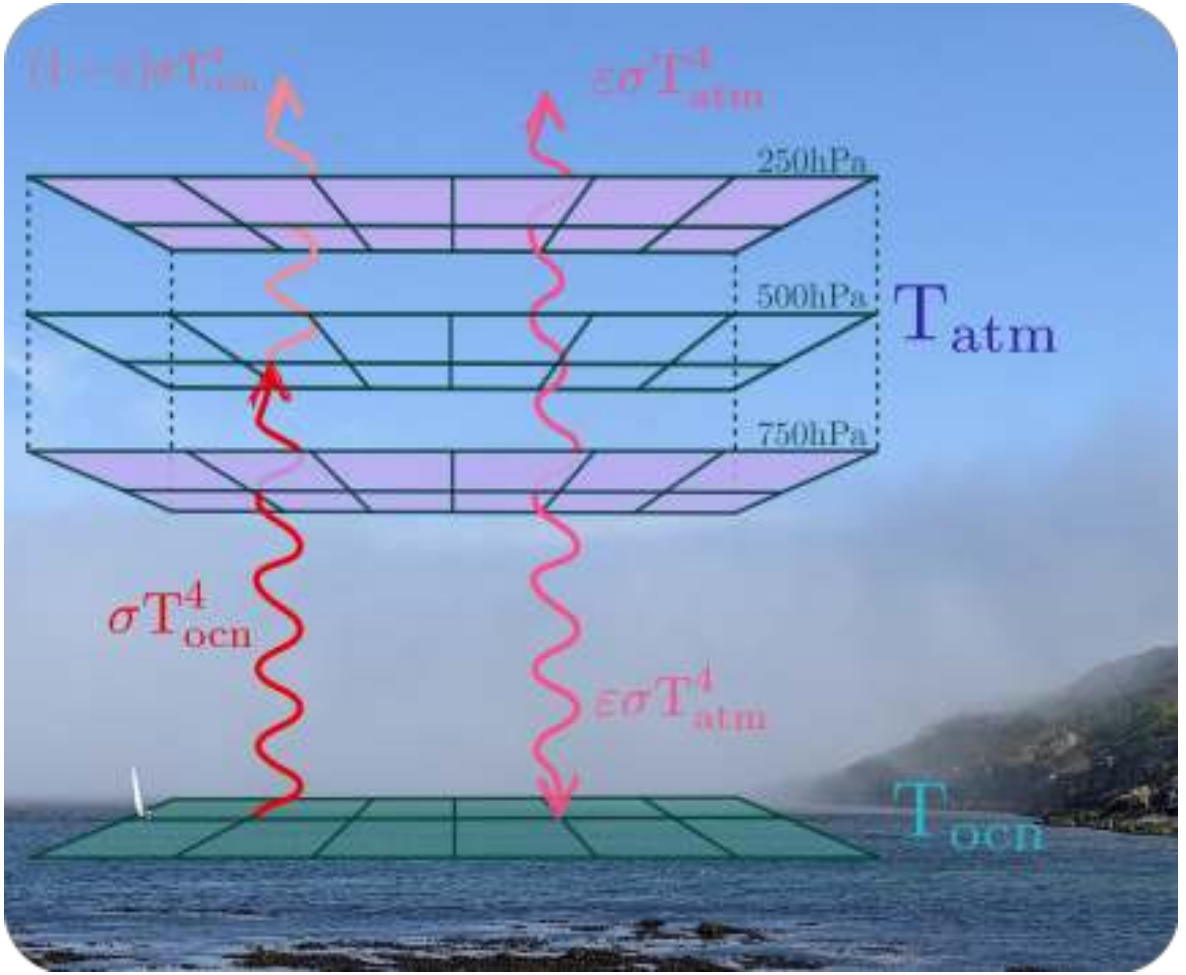
Model Summary

Model	T^4 Radiation Terms	T_0 Equilibrium Temperature
Linearised	Linearised	Constant
Dynamic Temperature	Linearised	Dynamic
Non-Linear	Non-Linearised	Dynamic

Key Points

Model Parameters

Emissivity ε



Model Parameters

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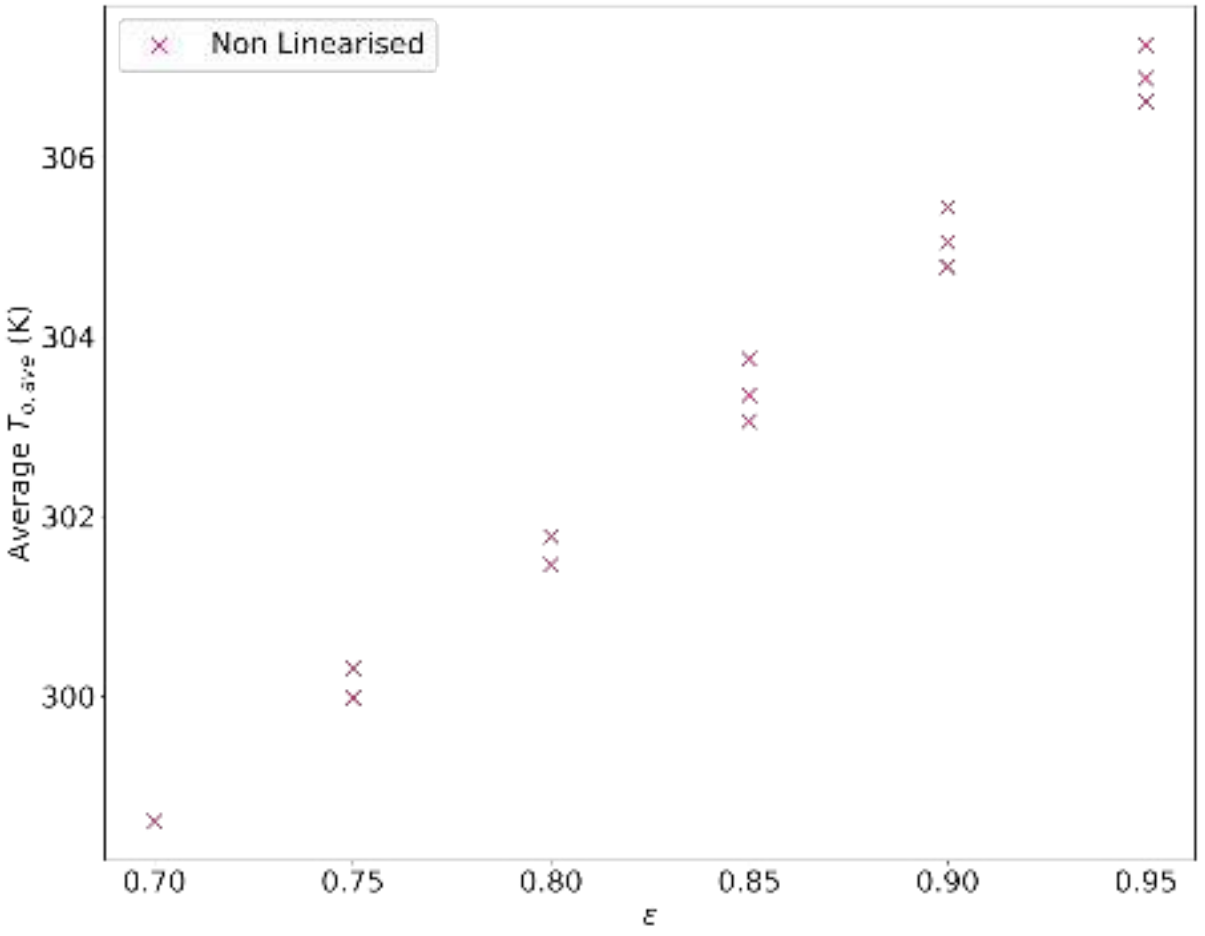

Model Parameters

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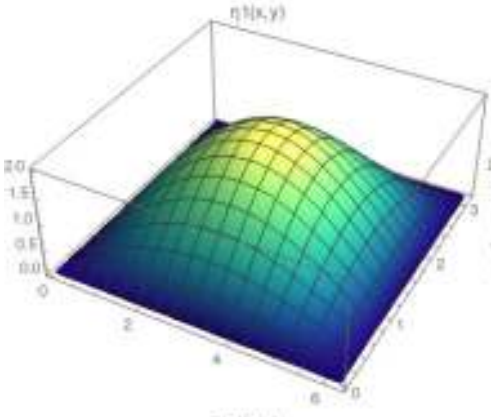

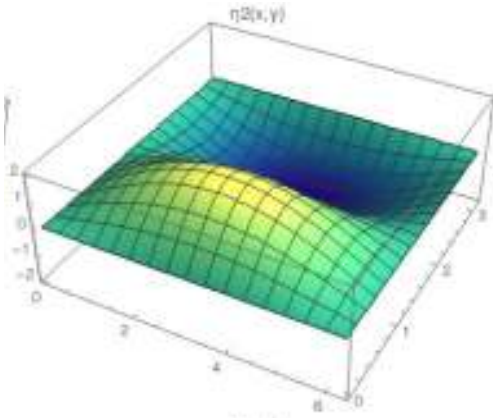

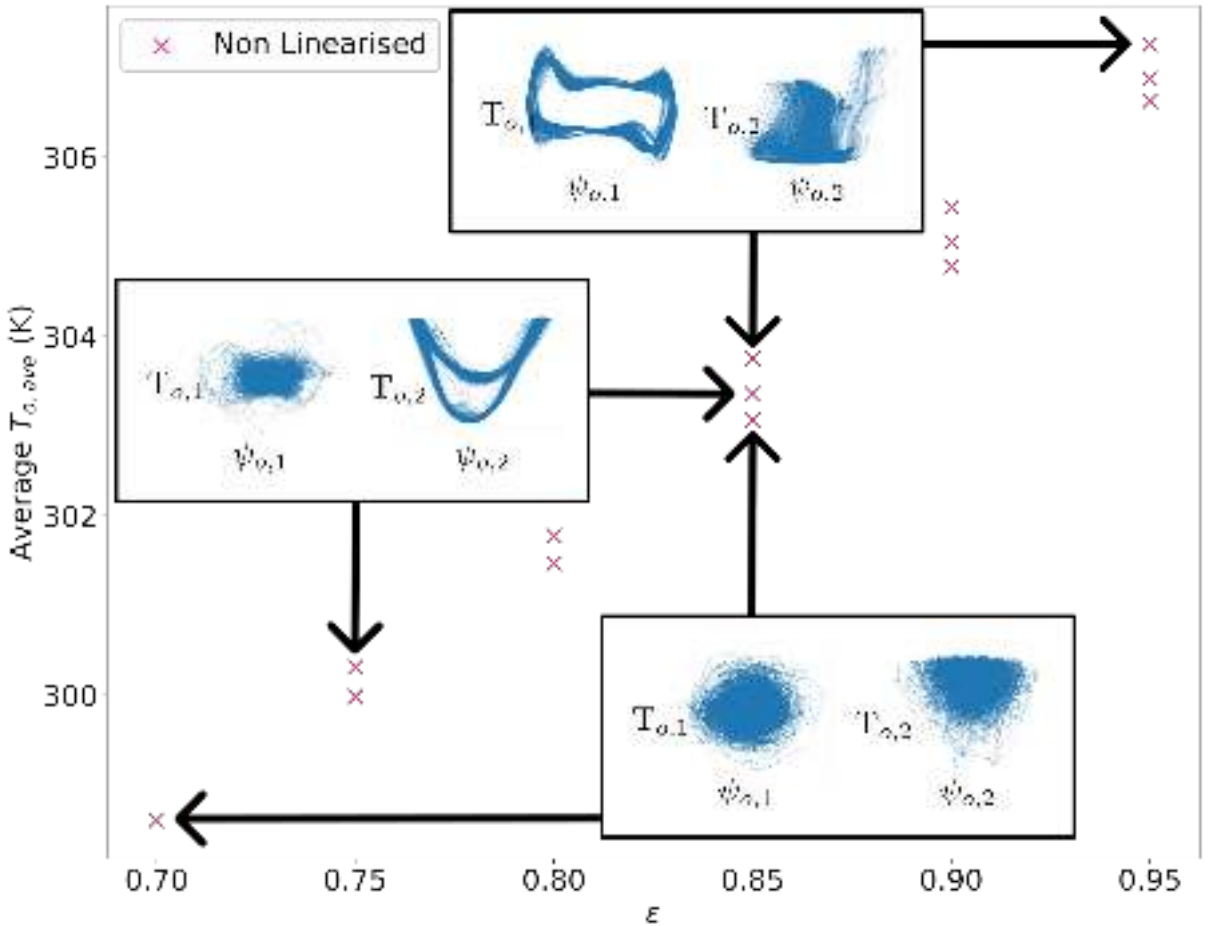

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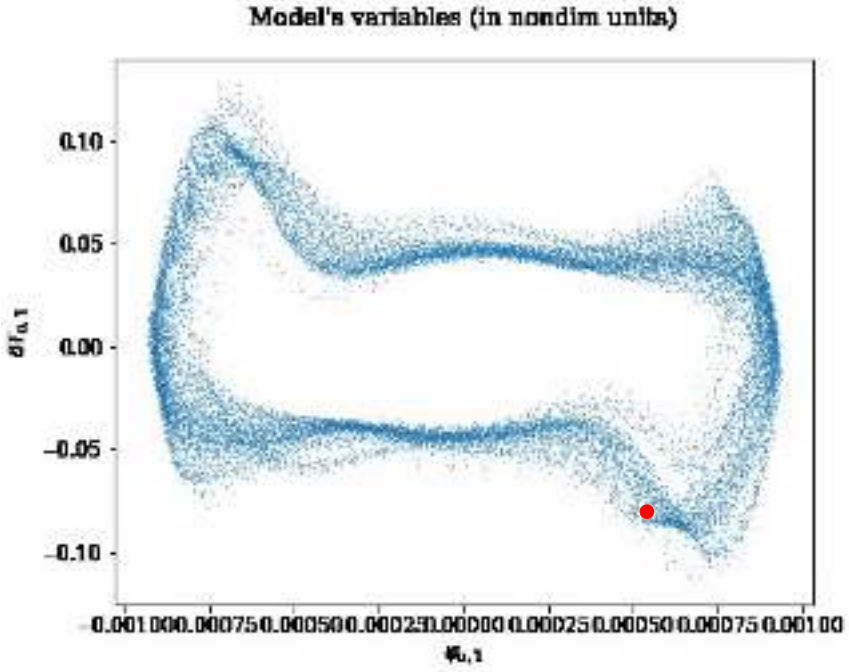

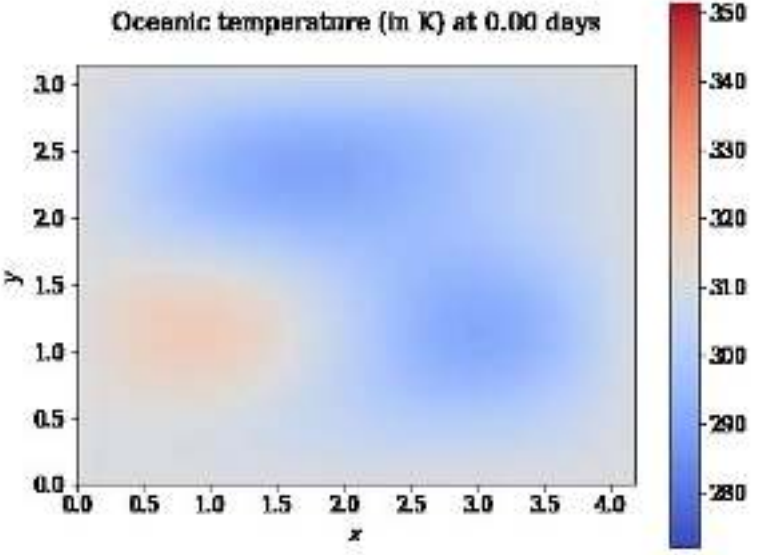

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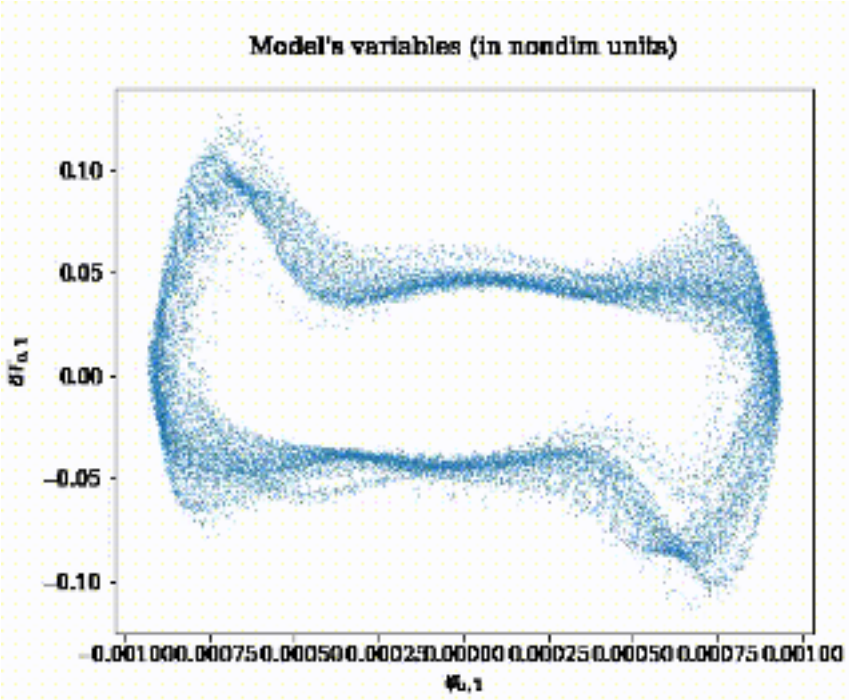

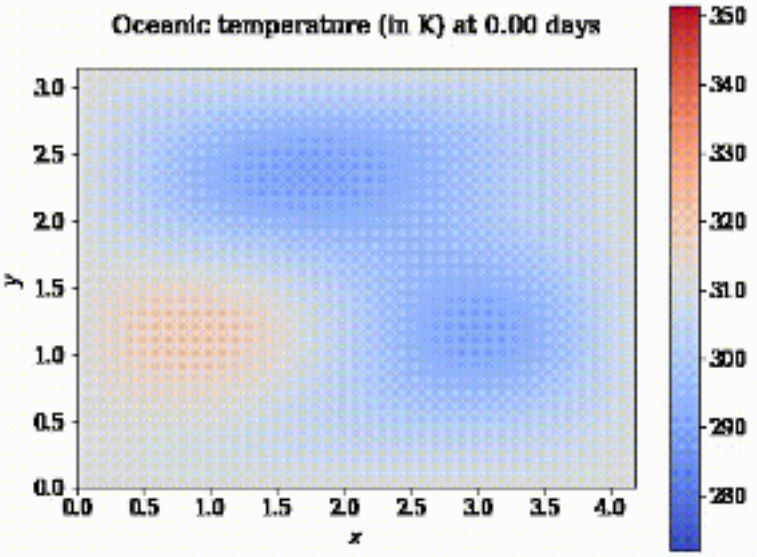

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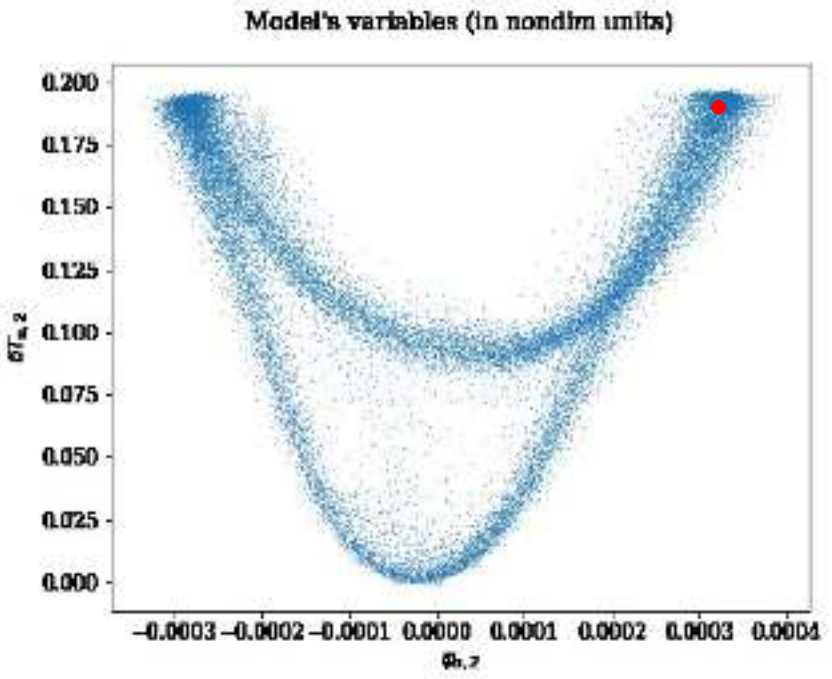

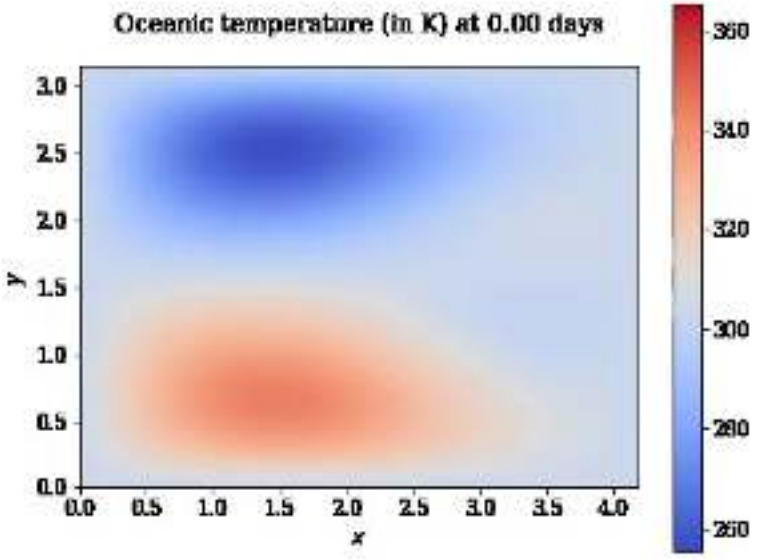

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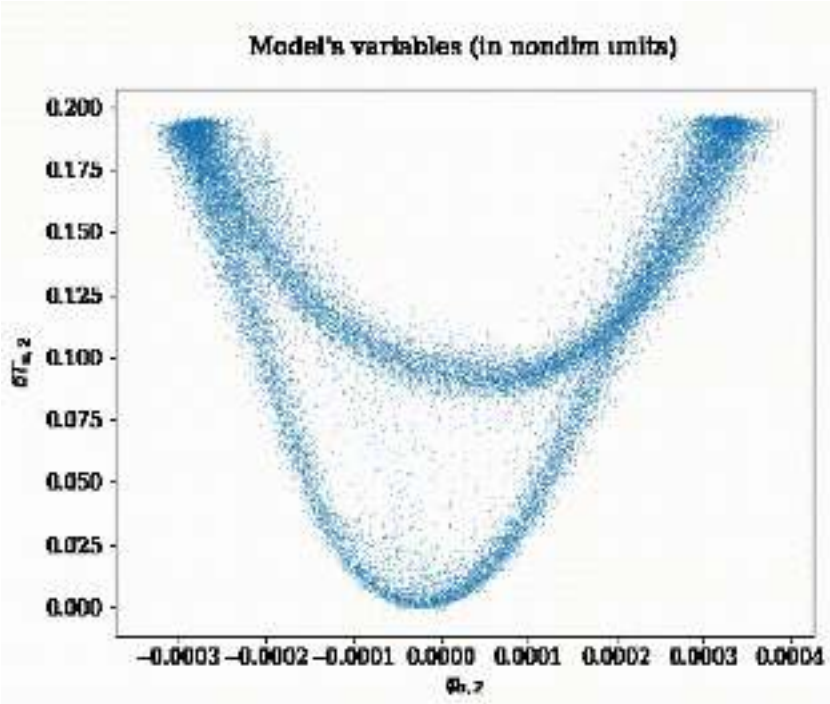
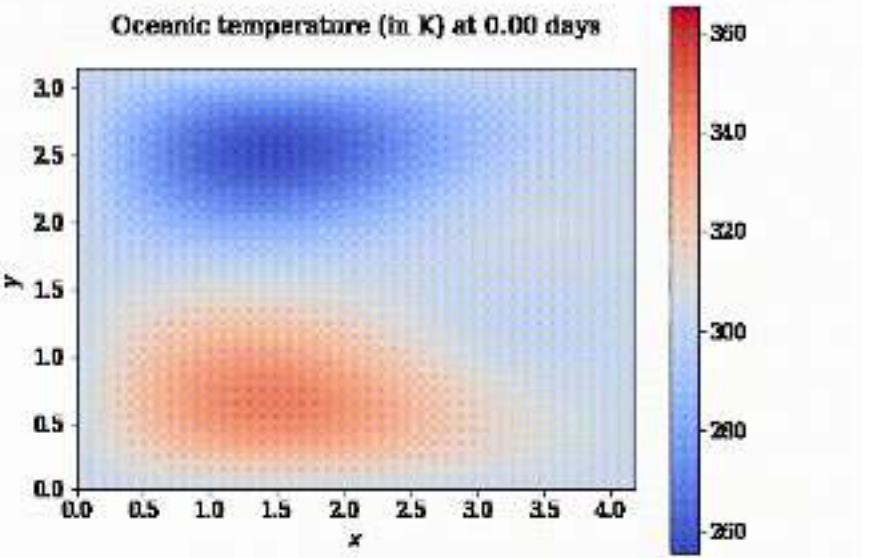
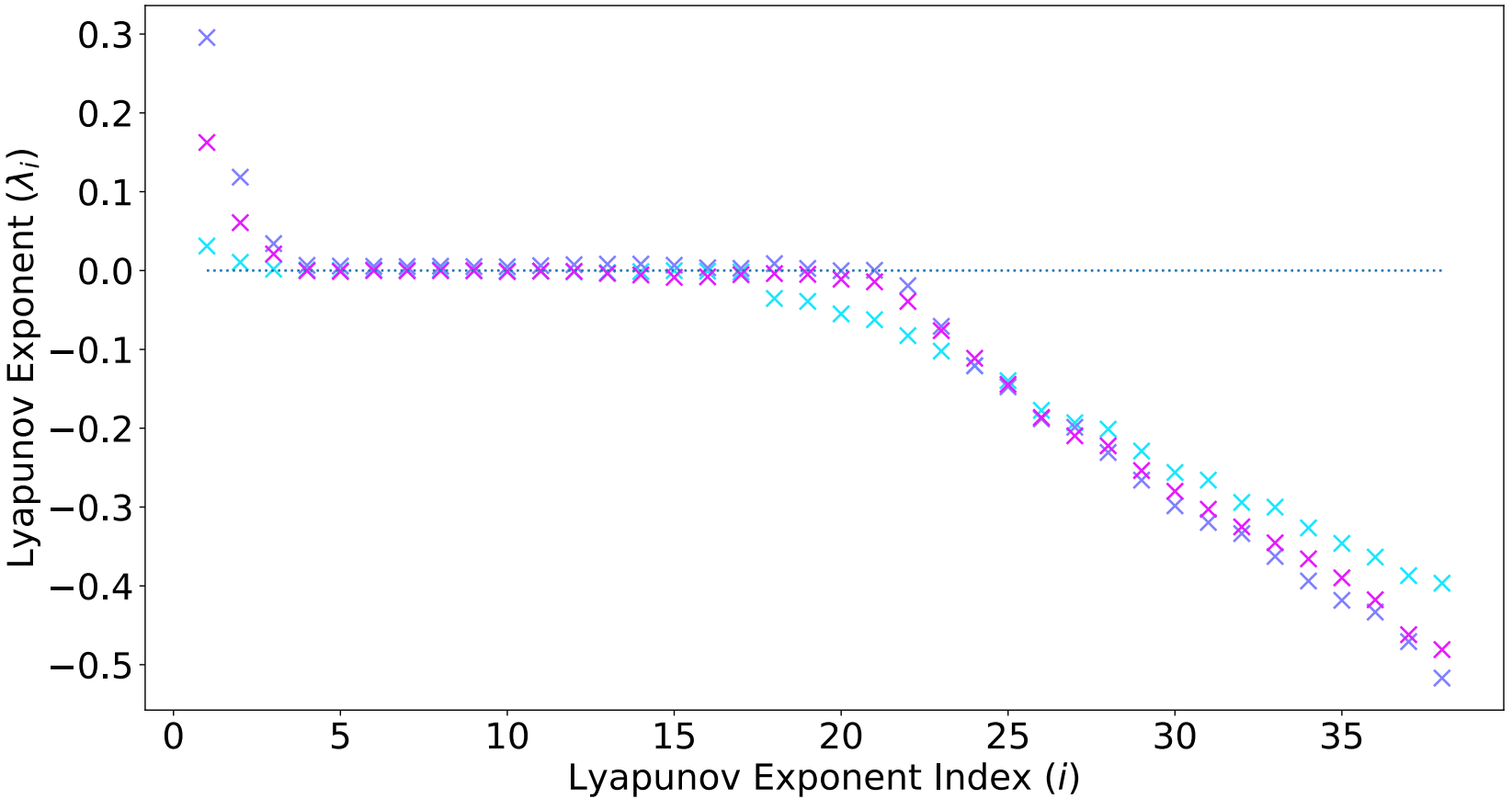




Model Outputs

Lyapunov Exponents



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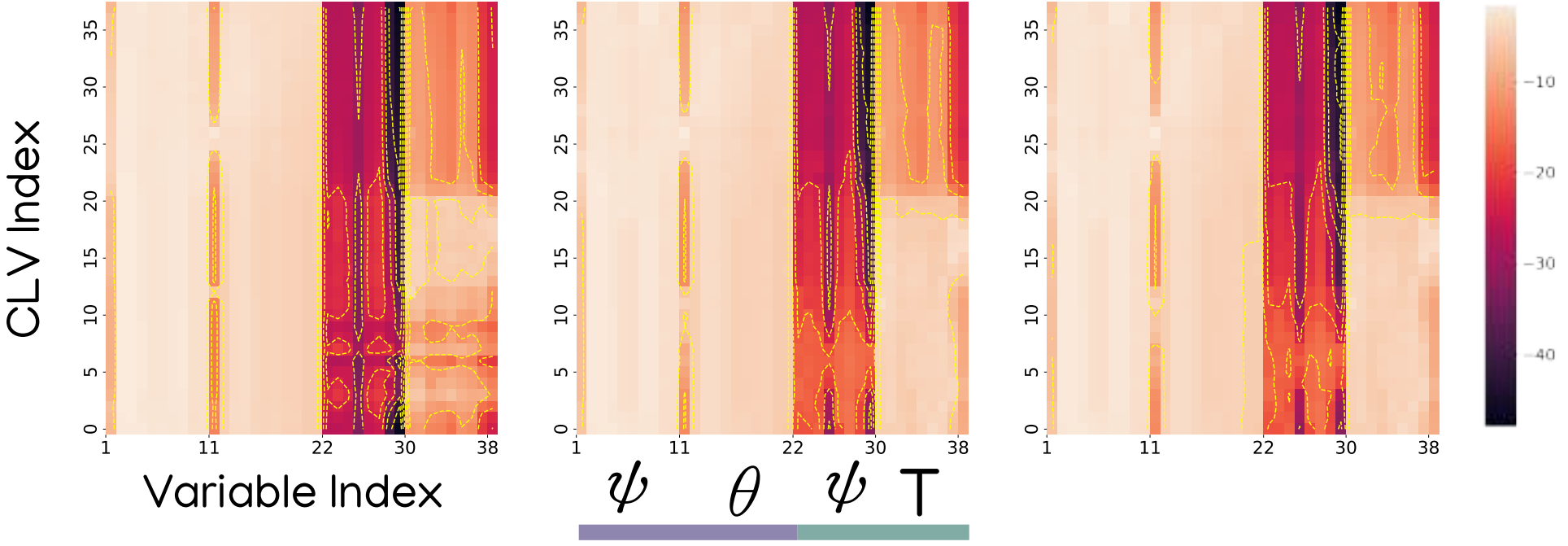

Conclusion

Non linear radiation terms produce temperature multi-stabilities

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Non linear radiation terms produce temperature multi-stabilities

Multi-stabilities produce distinct behaviour

Conclusion

Non linear radiation terms produce temperature multi–stabilities

Multi–stabilities produce distinct behaviour

Multi–stabilities in majority of cases produced by dynamic equilibria

Thank you

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De Cruz et al. (2016)
The Modular Arbitrary-Order Ocean-Atmosphere Model: MAOOAM v1.0