celestine

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CONTENTS:

1 celestine **1**
1.1 celestine package 1

2 Indices and tables **45**

Python Module Index **47**

Index **49**

CHAPTER

ONE

CELESTINE

1.1 celestine package

1.1.1 Subpackages

celestine.diagnostics package

Submodules

celestine.diagnostics.brine_drainage_parameterisation module

celestine.diagnostics.brine_drainage_parameterisation.**main**(*output_dir: Path*)

Module contents

celestine.enthalpy_method package

Submodules

celestine.enthalpy_method.common module

celestine.enthalpy_method.common.**calculate_common_enthalpy_method_vars**(*state:* EQMState | DISEQState, *cfg:* Config, *phase_masks*) → Tuple[ndarray[Any, dtype[_ScalarType_co]], ndarray[Any, dtype[_ScalarType_co]], ndarray[Any, dtype[_ScalarType_co]], ndarray[Any, dtype[_ScalarType_co]]]

celestine.enthalpy_method.enthalpy_method module

Module containing enthalpy method to calculate state variables from bulk enthalpy, bulk salinity and bulk gas.

celestine.enthalpy_method.enthalpy_method.**get_enthalpy_method**(*cfg: Config*) → Callable[[*EQMState* | *DISEQState*], *EQMStateFull* | *DISEQStateFull*]

celestine.enthalpy_method.gas module

celestine.enthalpy_method.gas.**calculate_DISEQ_dissolved_gas**(*state:* DISEQState, *liquid_fraction*, *physical_params:* EQMPhysicalParams | DISEQPhysicalParams, *phase_masks*) → ndarray[Any, dtype[_ScalarType_co]]

celestine.enthalpy_method.gas.**calculate_EQM_dissolved_gas**(*state:* EQMState, *liquid_fraction*, *physical_params:* EQMPhysicalParams | DISEQPhysicalParams) → ndarray[Any, dtype[_ScalarType_co]]

celestine.enthalpy_method.gas.**calculate_EQM_gas_fraction**(*state:* EQMState, *liquid_fraction: ndarray[Any, dtype[_ScalarType_co]]*, *physical_params:* EQMPhysicalParams | DISEQPhysicalParams) → ndarray[Any, dtype[_ScalarType_co]]

celestine.enthalpy_method.phase_boundaries module

Module for calculating the phase boundaries needed for the enthalpy method.

calculates the phase boundaries neglecting the gas fraction so that

$$\phi_s + \phi_l = 1$$

celestine.enthalpy_method.phase_boundaries.**get_phase_masks**(*state:* EQMState | DISEQState, *physical_params:* EQMPhysicalParams | DISEQPhysicalParams)

Module contents

celestine.equations package

Subpackages

celestine.equations.RJW14 package

Submodules

celestine.equations.RJW14.brine_channel_sink_terms module

`celestine.equations.RJW14.brine_channel_sink_terms.`**`get_brine_convection_sink`**(*cfg: Config*, *grids: Grids*) → Callable[[*EQMStateBCs* | *DISEQStateBCs*], ndarray[Any, dtype[_ScalarType_co]]]

celestine.equations.RJW14.brine_drainage module

Module to calculate the Rees Jones and Worster 2014 parameterisation for brine convection velocity and the strenght of the sink term.

Exports the functions:

calculate_brine_convection_liquid_velocity To be used in velocities module when using brine convection parameterisation.

calculate_brine_channel_sink To be used to add sink terms to conservation equations when using brine convection parameterisation.

`celestine.equations.RJW14.brine_drainage.`**`calculate_Rayleigh`**(*cell_centers*, *edge_grid*, *liquid_salinity*, *liquid_fraction*, *cfg: Config*)

Calculate the local Rayleigh number for brine convection as

$$\mathrm{Ra}(z) = \mathrm{Ra}_S K(z)(z+h)\Theta_l$$

Parameters

- **cell_centers** (*Numpy Array shape (I,)*) – The vertical coordinates of cell centers.
- **edge_grid** (*Numpy Array (size I+1)*) – The vertical coordinate positions of the edge grid.
- **liquid_salinity** (*Numpy Array shape (I,)*) – liquid salinity on center grid
- **liquid_fraction** (*Numpy Array (size I)*) – liquid fraction on center grid
- **cfg** (*celestine.params.Config*) – Configuration object for the simulation.

Returns

Array of shape (I,) of Rayleigh number at cell centers

`celestine.equations.RJW14.brine_drainage.`**`calculate_brine_channel_sink`**(*liquid_fraction*, *liquid_salinity*, *center_grid*, *edge_grid*, *cfg: Config*)

Calculate the sink term due to brine channels.

$$\text{sink} = \mathcal{A}$$

in the convecting region. Zero elsewhere.

NOTE: If no ice is present or if no convecting region exists returns zero

Parameters

- **liquid_fraction** (*Numpy Array of shape (I,)*) – liquid fraction on center grid
- **liquid_salinity** (*Numpy Array of shape (I,)*) – liquid salinity on center grid
- **center_grid** (*Numpy Array of shape (I,)*) – vertical coordinate of center grid
- **edge_grid** (*Numpy Array of shape (I+1,)*) – Vertical coordinates of cell edges
- **cfg** (*celestine.params.Config*) – Configuration object for the simulation.

Returns

Strength of the sink term due to brine channels on the center grid.

celestine.equations.RJW14.brine_drainage.**calculate_brine_channel_strength**(*Rayleigh_number*, *ice_depth*, *convecting_region_height*, *cfg: Config*)

Calculate the brine channel strength in the convecting region as

$$\mathcal{A} = \frac{\alpha \mathrm{Ra}_e}{(h + z_c)^2}$$

the effective Rayleigh number multiplied by a tuning parameter (Rees Jones and Worster 2014) over the convecting region thickness squared.

Parameters

- **Rayleigh_number** (*Numpy Array of shape (I,)*) – local Rayleigh number on center grid
- **ice_depth** (*float*) – depth of ice (positive)
- **convecting_region_height** (*float*) – position of the convecting region boundary (negative)
- **cfg** (*celestine.params.Config*) – Configuration object for the simulation.

Returns

Brine channel strength parameter

celestine.equations.RJW14.brine_drainage.**calculate_brine_convection_liquid_velocity**(*liquid_fraction*, *liquid_salinity*, *center_grid*, *edge_grid*, *cfg: Config*)

Calculate the vertical liquid Darcy velocity from Rees Jones and Worster 2014

$$W_l = \mathcal{A}(z_c - z)$$

in the convecting region. The velocity is stagnant above the convecting region. The velocity is constant in the liquid region and continuous at the interface.

NOTE: If no ice is present or if no convecting region exists returns zero velocity

Parameters

- **liquid_fraction** (*Numpy Array of shape (I,)*) – liquid fraction on center grid
- **liquid_salinity** (*Numpy Array of shape (I,)*) – liquid salinity on center grid
- **center_grid** (*Numpy Array of shape (I,)*) – vertical coordinate of center grid
- **edge_grid** (*Numpy Array of shape (I+1,)*) – Vertical coordinates of cell edges
- **cfg** (*celestine.params.Config*) – Configuration object for the simulation.

Returns
Liquid darcy velocity on the edge grid.

`celestine.equations.RJW14.brine_drainage.`**`calculate_integrated_mean_permeability`**(*z*, *liquid_fraction*, *ice_depth*, *cell_centers*, *cfg: Config*)

Calculate the harmonic mean permeability from the base of the ice up to the cell containing the specified z value using the expression of ReesJones2014.

$$K(z) = (\frac{1}{h+z}\int_{-h}^{z} \frac{1}{\Pi(\phi_l(z'))}dz')^{-1}$$

Parameters

- **z** (*float*) – height to integrate permeability up to
- **liquid_fraction** (*Numpy Array shape (I,)*) – liquid fraction on the center grid
- **ice_depth** (*float*) – positive depth position of ice ocean interface
- **cell_centers** (*Numpy Array of shape (I,)*) – cell center positions
- **cfg** (*celestine.params.Config*) – Configuration object for the simulation.

Returns
permeability averaged from base of the ice up to given z value

`celestine.equations.RJW14.brine_drainage.`**`calculate_permeability`**(*liquid_fraction*, *cfg: Config*)

Calculate the absolute permeability as a function of liquid fraction

$$\Pi(\phi_l) = \phi_l^3$$

Alternatively if the porosity threshold flag is true

$$\Pi(\phi_l) = \phi_l^2(\phi_l - \phi_c)$$

Parameters

- **liquid_fraction** (*Numpy Array*) – liquid fraction
- **cfg** (*celestine.params.Config*) – Configuration object for the simulation.

Returns
permeability on the same grid as liquid fraction

`celestine.equations.RJW14.brine_drainage.`**`get_convecting_region_height`**(*Rayleigh_number*, *edge_grid*, *cfg: Config*)

Calculate the height of the convecting region as the top edge of the highest cell in the domain for which the quantity

$$\mathrm{Ra}(z) - \mathrm{Ra}_c$$

is greater than or equal to zero.

NOTE: if no convecting region exists return np.NaN

Parameters

- **Rayleigh_number** (*Numpy Array of shape (I,)*) – local rayleigh number on center grid
- **edge_grid** (*Numpy Array (size I+1)*) – The vertical coordinate positions of the edge grid.
- **cfg** (*celestine.params.Config*) – Configuration object for the simulation.

Returns

Edge grid value at convecting boundary.

`celestine.equations.RJW14.brine_drainage.`**`get_effective_Rayleigh_number`**`(`*Rayleigh_number*, *cfg: Config*`)`

Calculate the effective Rayleigh Number as the maximum of

$$\mathrm{Ra}(z) - \mathrm{Ra}_c$$

in the convecting region.

NOTE: if no convecting region exists returns 0.

Parameters

- **Rayleigh_number** (*Numpy Array of shape (I,)*) – local rayleigh number on center grid
- **cfg** (*celestine.params.Config*) – Configuration object for the simulation.

Returns

Effective Rayleigh number.

Module contents

Module to calculate the sink terms for conservation equations when using the Rees Jones and Worster 2014 brine drainage parameterisation.

These terms represent loss through the brine channels and need to be added in the convecting region when using this parameterisation

celestine.equations.flux package

Submodules

celestine.equations.flux.bulk_dissolved_gas_flux module

calculate the flux terms for the dissolved gas equation in DISEQ model

celestine.equations.flux.bulk_dissolved_gas_flux.**calculate_bulk_dissolved_gas_flux**(*state_BCs*, *Wl*, *V*, *D_g*, *cfg*)

celestine.equations.flux.bulk_gas_flux module

celestine.equations.flux.bulk_gas_flux.**calculate_advective_dissolved_gas_flux**(*dissolved_gas*, *Wl*, *cfg*)

celestine.equations.flux.bulk_gas_flux.**calculate_bubble_gas_flux**(*gas_fraction*, *Vg*)

celestine.equations.flux.bulk_gas_flux.**calculate_diffusive_gas_flux**(*dissolved_gas*, *liquid_fraction*, *D_g*, *cfg*)

celestine.equations.flux.bulk_gas_flux.**calculate_frame_advection_gas_flux**(*gas*, *V*)

celestine.equations.flux.bulk_gas_flux.**calculate_gas_flux**(*state_BCs*, *Wl*, *V*, *Vg*, *D_g*, *cfg*)

celestine.equations.flux.gas_fraction_flux module

Calculate gas phase fluxes for disequilibrium model

celestine.equations.flux.gas_fraction_flux.**calculate_gas_fraction_flux**(*state_BCs*, *V*, *Vg*)

celestine.equations.flux.heat_flux module

celestine.equations.flux.heat_flux.**calculate_advective_heat_flux**(*temperature*, *Wl*)

celestine.equations.flux.heat_flux.**calculate_conductive_heat_flux**(*state_BCs*, *D_g*, *cfg*)

Calculate conductive heat flux as

$$-\frac{\partial\theta}{\partial z}$$

or alteratively if the phase_average_conductivity configuration parameter is set to True then we use the conductivity ratio as follows

$$-[(\phi_l+\lambda\phi_s)\frac{\partial\theta}{\partial z}]$$

Parameters

- **temperature** (*Numpy Array of size I+2*) – temperature including ghost cells
- **D_g** (*Numpy Array*) – difference matrix for ghost grid

- **cfg** (*celestine.params.Config*) – Simulation configuration

Returns
conductive heat flux

celestine.equations.flux.heat_flux.**calculate_frame_advection_heat_flux**(*enthalpy*, *V*)

celestine.equations.flux.heat_flux.**calculate_heat_flux**(*state_BCs*, *Wl*, *V*, *D_g*, *cfg*)

celestine.equations.flux.salt_flux module

celestine.equations.flux.salt_flux.**calculate_advective_salt_flux**(*liquid_salinity*, *Wl*, *cfg*)

celestine.equations.flux.salt_flux.**calculate_diffusive_salt_flux**(*liquid_salinity*, *liquid_fraction*, *D_g*, *cfg*)

Take liquid salinity and liquid fraction on ghost grid and interpolate liquid fraction geometrically

celestine.equations.flux.salt_flux.**calculate_frame_advection_salt_flux**(*salt*, *V*)

celestine.equations.flux.salt_flux.**calculate_salt_flux**(*state_BCs*, *Wl*, *V*, *D_g*, *cfg*)

Module contents

Module for calculating the fluxes using upwind scheme

celestine.equations.flux.**get_dz_fluxes**(*cfg: Config*, *grids: Grids*) → Callable[[*EQMStateBCs* | *DISEQStateBCs*, ndarray[Any, dtype[_ScalarType_co]], ndarray[Any, dtype[_ScalarType_co]], ndarray[Any, dtype[_ScalarType_co]]], ndarray[Any, dtype[_ScalarType_co]]]

celestine.equations.velocities package

Submodules

celestine.equations.velocities.bubble_parameters module

celestine.equations.velocities.bubble_parameters.**calculate_bubble_size_fraction**(*bubble_radius_scaled*, *liquid_fraction*, *cfg: Config*)

Takes bubble radius scaled and liquid fraction on edges and calculates the bubble size fraction as

$$\lambda = \Lambda/(\phi_l^q + \mathrm{reg})$$

Returns the bubble size fraction on the edge grid.

celestine.equations.velocities.mono_distribution module

`celestine.equations.velocities.mono_distribution.`**`calculate_lag_function`**(*bubble_size_fraction*)

Calculate lag function from bubble size fraction on edge grid as

$$G(\lambda) = 1 - \lambda/2$$

for 0<lambda<1. Edge cases are given by G(0)=1 and G(1) = 0.5 for values outside this range.

`celestine.equations.velocities.mono_distribution.`**`calculate_mono_lag_factor`**(*liquid_fraction*, *cfg: Config*)

Take liquid fraction on the ghost grid and calculate the lag factor for a mono bubble size distribution as

$$I_2 = G(\lambda)$$

returns lag factor on the edge grid

`celestine.equations.velocities.mono_distribution.`**`calculate_mono_wall_drag_factor`**(*liquid_fraction*, *cfg: Config*)

Take liquid fraction on the ghost grid and calculate the wall drag factor for a mono bubble size distribution as

$$I_1 = \frac{\lambda^2}{K(\lambda)}$$

returns wall drag factor on the edge grid

`celestine.equations.velocities.mono_distribution.`**`calculate_wall_drag_function`**(*bubble_size_fraction*, *cfg: Config*)

Calculate wall drag function from bubble size fraction on edge grid as

$$\frac{1}{K(\lambda)} = (1 - \lambda)^r$$

in the power law case or in the Haberman case from the paper

$$\frac{1}{K(\lambda)} = \frac{1 - 1.5\lambda + 1.5\lambda^5 - \lambda^6}{1 + 1.5\lambda^5}$$

for 0<lambda<1. Edge cases are given by K(0)=1 and K(1) = 0 for values outside this range.

celestine.equations.velocities.power_law_distribution module

`celestine.equations.velocities.power_law_distribution.`**`calculate_lag_integral`**(*bubble_size_fraction_min: float*, *bubble_size_fraction_max: float*, *cfg: Config*)

`celestine.equations.velocities.power_law_distribution.`**`calculate_lag_integrand`**(*bubble_size_fraction: float*, *cfg: Config*)

Scalar function to calculate lag integrand for polydispersive case.

Bubble size fraction is given as a scalar input to calculate

$$\lambda^{3-p} G(\lambda)$$

`celestine.equations.velocities.power_law_distribution.`**`calculate_power_law_lag_factor`**(*liquid_fraction*, *cfg:* Config)

Take liquid fraction on the ghost grid and calculate the lag factor for power law bubble size distribution.

Return on edge grid

`celestine.equations.velocities.power_law_distribution.`**`calculate_power_law_wall_drag_factor`**(*liquid_fraction*, *cfg:* Config)

Take liquid fraction on the ghost grid and calculate the wall drag factor for power law bubble size distribution.

Return on edge grid

`celestine.equations.velocities.power_law_distribution.`**`calculate_volume_integrand`**(*bubble_size_fraction: float*, *cfg:* Config)

Scalar function to calculate the integrand for volume under a power law bubble size distribution given as

$$\lambda^{3-p}$$

in terms of the bubble size fraction.

`celestine.equations.velocities.power_law_distribution.`**`calculate_wall_drag_integral`**(*bubble_size_fraction_min: float*, *bubble_size_fraction_max: float*, *cfg:* Config)

`celestine.equations.velocities.power_law_distribution.`**`calculate_wall_drag_integrand`**(*bubble_size_fraction: float*, *cfg:* Config)

Scalar function to calculate wall drag integrand for polydispersive case.

Bubble size fraction is given as a scalar input to calculate

$$\frac{\lambda^{5-p}}{K(\lambda)}$$

where the wall drag enhancement funciton K can be given by a power law fit or taken from the Haberman paper.

celestine.equations.velocities.velocities module

`celestine.equations.velocities.velocities.`**`calculate_frame_velocity`**(*cfg:* Config)

`celestine.equations.velocities.velocities.`**`calculate_gas_interstitial_velocity`**(*liquid_fraction*, *liquid_darcy_velocity*, *wall_drag_factor*, *lag_factor*, *cfg:* Config)

Calculate Vg from liquid fraction on the ghost frid and liquid interstitial velocity

$$V_g = \mathcal{B}(\phi_l^{2q} I_1) + U_0 I_2$$

Return Vg on edge grid

`celestine.equations.velocities.velocities.`**`calculate_liquid_darcy_velocity`**(*liquid_fraction*, *liquid_salinity*, *center_grid*, *edge_grid*, *cfg:* Config)

Calculate liquid Darcy velocity either using brine convection parameterisation or as stagnant

Parameters

- **liquid_fraction** (*Numpy Array (size I+2)*) – liquid fraction on ghost grid
- **liquid_salinity** (*Numpy Array (size I+2)*) – liquid salinity on ghost grid
- **center_grid** (*Numpy Array of shape (I,)*) – vertical coordinates of cell centers
- **edge_grid** (*Numpy Array (size I+1)*) – Vertical coordinates of cell edges
- **cfg** (*celestine.params.Config*) – simulation configuration object

Returns

liquid darcy velocity on edge grid

`celestine.equations.velocities.velocities.`**`calculate_velocities`**(*state_BCs*, *cfg:* Config)

Inputs on ghost grid, outputs on edge grid

needs the simulation config, liquid fraction, liquid salinity and grids

Module contents

Module to calculate Darcy velocities.

The liquid Darcy velocity must be parameterised.

The gas Darcy velocity is calculated as gas_fraction x interstitial bubble velocity

Interstitial bubble velocity is found by a steady state Stoke's flow calculation. We have implemented two cases mono: All bubbles nucleate and remain the same size power_law: A power law bubble size distribution with fixed max and min.

Submodules

celestine.equations.equations module

`celestine.equations.equations.`**`get_equations`**(*cfg:* Config, *grids*) → Callable[[*EQMStateBCs* | *DISEQStateBCs*], ndarray[Any, dtype[_ScalarType_co]]]

celestine.equations.nucleation module

`celestine.equations.nucleation.get_nucleation`(*cfg: Config*) → Callable[[*EQMStateBCs* | *DISEQStateBCs*], ndarray[Any, dtype[_ScalarType_co]]]

celestine.equations.radiative_heating module

Calculate internal shortwave radiative heating due to oil droplets

`celestine.equations.radiative_heating.get_radiative_heating`(*cfg: Config*, *grids: Grids*) → Callable[[*EQMStateBCs* | *DISEQStateBCs*], ndarray[Any, dtype[_ScalarType_co]]]

Calculate internal shortwave heating source for enthalpy equation.

if the RadForcing object is given as the forcing config then calculates internal heating based on the object given in the configuration for oil_heating.

If another forcing is chosen then just returns a function to create an array of zeros as no internal heating is calculated.

Module contents

celestine.forcing package

Subpackages

celestine.forcing.surface_energy_balance package

Submodules

celestine.forcing.surface_energy_balance.surface_energy_balance module

Module to compute the surface heat flux from geophysical energy balance

following [1]

Refs: [1] P. D. Taylor and D. L. Feltham, 'A model of melt pond evolution on sea ice', J. Geophys. Res., vol. 109, no. C12, p. 2004JC002361, Dec. 2004, doi: 10.1029/2004JC002361.

`celestine.forcing.surface_energy_balance.surface_energy_balance.calculate_emissivity`(*cfg: Config*, *top_cell_is_ice: bool*) → float `celestine.forcing.surface_energy_balance.surface_energy_balance.`**`calculate_total_heat_flux`**(*cfg:* Config, *time:* *float*, *top_cell_is_ice:* *bool*, *surface_temp:* *float*) → float

Takes non-dimensional surface temperature and returns non-dimensional heat flux

`celestine.forcing.surface_energy_balance.surface_energy_balance.`**`convert_surface_temperature_to_kelvin`**(*cf* C fi *nc* *fl* → fl

`celestine.forcing.surface_energy_balance.surface_energy_balance.`**`find_ghost_cell_temperature`**(*state:* EQMStateFull | DISEQStateFull, *cfg:* Config) → float

`celestine.forcing.surface_energy_balance.surface_energy_balance.`**`solve_for_surface_temp`**(*cfg:* Config, *time:* *float*, *top_cell_solid_fractio* *float*, *top_cell_center_temp* *float*, *second_cell_center_temp* *float*) → float

Returns non dimensional surface temperature celestine.forcing.surface_energy_balance.surface_energy_balance.**surface_temp_gradient**(*cfg: Config*, *surface_temp: float*, *top_cell_center_temp: float*, *second_cell_center_temp: float*) → float

Approximate non dimensional temperature gradient using the unknown surface temperature value (top of edge grid) and the top two known temperature values on the center grid

celestine.forcing.surface_energy_balance.surface_energy_balance.**top_cell_conductivity**(*cfg: Config*, *solid_fraction: float*) → float

celestine.forcing.surface_energy_balance.turbulent_heat_flux module

Module to compute the turbulent atmospheric sensible and latent heat fluxes

All temperatures are in Kelvin in this module

Refs: [1] P. D. Taylor and D. L. Feltham, 'A model of melt pond evolution on sea ice', J. Geophys. Res., vol. 109, no. C12, p. 2004JC002361, Dec. 2004, doi: 10.1029/2004JC002361.

[2] E. E. Ebert and J. A. Curry, 'An intermediate one-dimensional thermodynamic sea ice model for investigating ice-atmosphere interactions', Journal of Geophysical Research: Oceans, vol. 98, no. C6, pp. 10085–10109, 1993, doi: 10.1029/93JC00656.

celestine.forcing.surface_energy_balance.turbulent_heat_flux.**calculate_bulk_transfer_coefficient**(*cfg: Config*, *top_cell_*, *bool*, *time: float*, *surface_tem*, *float*) → float

Calculation of bulk transfer coeff from [2] `celestine.forcing.surface_energy_balance.turbulent_heat_flux.`**`calculate_latent_heat_flux`**(*cfg:* Config, *time:* *float*, *top_cell_is_ice:* *bool*, *surface_temp:* *float*) → float

Calculate latent heat flux from [2]

`celestine.forcing.surface_energy_balance.turbulent_heat_flux.`**`calculate_ref_air_temp`**(*cfg:* Config, *time:* *float*) → float

return air temperature at reference level above the ice in Kelvin

in the configuration the air temperature is given in deg C

`celestine.forcing.surface_energy_balance.turbulent_heat_flux.`**`calculate_ref_atmospheric_pressure`**(*cfg:* Config, *time:* *float*) → float

return atmospheric pressure at reference level above the ice

`celestine.forcing.surface_energy_balance.turbulent_heat_flux.`**`calculate_ref_specific_humidity`**(*cfg:* Config, *time:* *float*) → float

return specific humidity at reference level above the ice

`celestine.forcing.surface_energy_balance.turbulent_heat_flux.`**`calculate_ref_windspeed`**(*cfg:* Config, *time:* *float*) → float

return windspeed at reference level above the ice celestine.forcing.surface_energy_balance.turbulent_heat_flux.**calculate_sensible_heat_flux**(*cfg: Config*, *time: float*, *top_cell_is_ice: bool*, *surface_temp: float*) → float

Calculate sensible heat flux from [2]

celestine.forcing.surface_energy_balance.turbulent_heat_flux.**calculate_surface_specific_humidity**(*cfg: Config*, *time: float*, *surface_temp: float*) → float

Following expression given in [1]

Module contents

Submodules

celestine.forcing.boundary_conditions module

Module to provide functions to add boundary conditions to each quantity on the centered grid that needs to be on the ghost grid for the upwind scheme.

celestine.forcing.boundary_conditions.**get_boundary_conditions**(*cfg: Config*) → Callable[[*EQMStateFull* | *DISEQStateFull*], *EQMStateBCs* | *DISEQStateBCs*]

celestine.forcing.radiative_forcing module

Module for providing surface radiative forcing to simulation.

Currently only total surface shortwave irradiance (integrated over entire shortwave part of the spectrum) is provided and this is used to calculate internal radiative heating.

Unlike temperature forcing this provides dimensional forcing

celestine.forcing.radiative_forcing.**get_LW_forcing**(*time: float*, *cfg: Config*) → float

celestine.forcing.radiative_forcing.**get_SW_forcing**(*time*, *cfg: Config*)

celestine.forcing.temperature_forcing module

Module for providing surface temperature forcing to simulation.

Note that the barrow temperature data is read in from a file if needed by the simulation configuration.

`celestine.forcing.temperature_forcing.`**`get_bottom_temperature_forcing`**(*time*, *cfg: Config*)

`celestine.forcing.temperature_forcing.`**`get_temperature_forcing`**(*state: EQMStateFull | DISEQStateFull*, *cfg: Config*)

Module contents

celestine.params package

Subpackages

celestine.params.dimensional package

Submodules

celestine.params.dimensional.bubble module

`class` `celestine.params.dimensional.bubble.`**`DimensionalBaseBubbleParams`**(*pore_radius: float = 0.001*, *pore_throat_scaling: float = 0.5*, *porosity_threshold: bool = False*, *porosity_threshold_value: float = 0.024*, *escape_ice_surface: bool = True*)

Bases: `object`

`escape_ice_surface: bool = True`

`pore_radius: float = 0.001`

`pore_throat_scaling: float = 0.5`

`porosity_threshold: bool = False`

`porosity_threshold_value: float = 0.024`

class celestine.params.dimensional.bubble.**DimensionalMonoBubbleParams**(*pore_radius: float = 0.001*, *pore_throat_scaling: float = 0.5*, *porosity_threshold: bool = False*, *porosity_threshold_value: float = 0.024*, *escape_ice_surface: bool = True*, *bubble_radius: float = 0.001*)

Bases: *DimensionalBaseBubbleParams*

bubble_radius: float = 0.001

property bubble_radius_scaled

calculate the bubble radius divided by the pore scale

$$\Lambda = R_B/R_0$$

class celestine.params.dimensional.bubble.**DimensionalPowerLawBubbleParams**(*pore_radius: float = 0.001*, *pore_throat_scaling: float = 0.5*, *porosity_threshold: bool = False*, *porosity_threshold_value: float = 0.024*, *escape_ice_surface: bool = True*, *bubble_distribution_power: float = 1.5*, *minimum_bubble_radius: float = 1e-06*, *maximum_bubble_radius: float = 0.001*)

Bases: *DimensionalBaseBubbleParams*

bubble_distribution_power: float = 1.5

maximum_bubble_radius: float = 0.001

property maximum_bubble_radius_scaled

calculate the bubble radius divided by the pore scale

$$\Lambda = R_B/R_0$$

minimum_bubble_radius: float = 1e-06

property minimum_bubble_radius_scaled

calculate the bubble radius divided by the pore scale

$$\Lambda = R_B/R_0$$

celestine.params.dimensional.convection module

`class celestine.params.dimensional.convection.DimensionalRJW14Params`(*couple_bubble_to_horizontal_flow: bool = False*, *couple_bubble_to_vertical_flow: bool = False*, *Rayleigh_critical: float = 2.9*, *convection_strength: float = 0.13*, *haline_contraction_coefficient: float = 0.00075*, *reference_permeability: float = 1e-08*)

Bases: `object`

Rayleigh_critical: float = 2.9

convection_strength: float = 0.13

couple_bubble_to_horizontal_flow: bool = False

couple_bubble_to_vertical_flow: bool = False

haline_contraction_coefficient: float = 0.00075

reference_permeability: float = 1e-08

`class celestine.params.dimensional.convection.NoBrineConvection`

Bases: `object`

No brine convection

celestine.params.dimensional.dimensional module

Dimensional parameters required to run a simulation and convert output to dimensional variables.

The DimensionalParams class contains all the dimensional parameters needed to produce a simulation configuration.

The Scales class contains all the dimensional parameters required to convert simulation output between physical and non-dimensional variables.

class celestine.params.dimensional.dimensional.**DimensionalParams**(*name: str*, *total_time_in_days: float*, *savefreq_in_days: float*, *lengthscale: float*, *gas_params:* DimensionalEQMGasParams | DimensionalDISEQGasParams, *bubble_params:* DimensionalMonoBubbleParams | DimensionalPowerLawBubbleParams, *brine_convection_params:* DimensionalRJW14Params | NoBrineConvection, *forcing_config:* DimensionalRadForcing | DimensionalBRW09Forcing | DimensionalConstantForcing | DimensionalYearlyForcing, *initial_conditions_config:* DimensionalOilInitialConditions | UniformInitialConditions | BRW09InitialConditions, *water_params:* DimensionalWaterParams = *DimensionalWaterParams(liquid_density=1028, ocean_salinity=34, eutectic_salinity=270, eutectic_temperature=-21.1, ocean_temperature=-0.81, latent_heat=334000.0, specific_heat_capacity=4184, phase_average_conductivity=False, liquid_thermal_conductivity=0.54, solid_thermal_conductivity=2.22, salt_diffusivity=0, liquid_viscosity=0.00278)*, *numerical_params:* NumericalParams = *NumericalParams(I=50, regularisation=1e-06)*, *frame_velocity_dimensional: float = 0*, *gravity: float = 9.81*)

Bases: `object`

Contains all dimensional parameters needed to calculate non dimensional numbers.

To see the units each input should have look at the comment next to the default value.

property B

calculate the non dimensional scale for buoyant rise of gas bubbles as

$$\mathcal{B} = \frac{\rho_l g R_0^2 h}{3\mu\kappa}$$

property Rayleigh_salt

Calculate the haline Rayleigh number as

$$\mathrm{Ra}_S = \frac{\rho_l g \beta \Delta S H K_0}{\kappa \mu}$$

brine_convection_params: *DimensionalRJW14Params* | *NoBrineConvection*

bubble_params: *DimensionalMonoBubbleParams* | *DimensionalPowerLawBubbleParams*

property damkohler_number

Return damkohler number as ratio of thermal timescale to nucleation timescale

property expansion_coefficient

calculate

$$\chi = \rho_l \xi_{\text{sat}} / \rho_g$$

forcing_config: *DimensionalRadForcing* | *DimensionalBRW09Forcing* | *DimensionalConstantForcing* | *DimensionalYearlyForcing*

property frame_velocity

calculate the frame velocity in non dimensional units

frame_velocity_dimensional: float = 0

gas_params: *DimensionalEQMGasParams* | *DimensionalDISEQGasParams*

gravity: float = 9.81

initial_conditions_config: *DimensionalOilInitialConditions* | *UniformInitialConditions* | *BRW09InitialConditions*

lengthscale: float

property lewis_gas

Calculate the lewis number for dissolved gas, return np.inf if there is no dissolved gas diffusion.

$$\mathrm{Le}_\xi = \kappa / D_\xi$$

classmethod load(*path*)

load this object from a yaml configuration file.

name: str

numerical_params: *NumericalParams* **= NumericalParams(I=50, regularisation=1e-06)**

save(*directory: Path*)

save this object to a yaml file in the specified directory.

The name will be the name given with _dimensional appended to distinguish it from a saved non-dimensional configuration.

property savefreq

calculate the save frequency in non dimensional time

savefreq_in_days: float

property scales

return a Scales object used for converting between dimensional and non dimensional variables.

property total_time

calculate the total time in non dimensional units for the simulation

total_time_in_days: float

water_params: *DimensionalWaterParams* **= DimensionalWaterParams(liquid_density=1028, ocean_salinity=34, eutectic_salinity=270, eutectic_temperature=-21.1, ocean_temperature=-0.81, latent_heat=334000.0, specific_heat_capacity=4184, phase_average_conductivity=False, liquid_thermal_conductivity=0.54, solid_thermal_conductivity=2.22, salt_diffusivity=0, liquid_viscosity=0.00278)**

celestine.params.dimensional.forcing module

class celestine.params.dimensional.forcing.**DimensionalBRW09Forcing**(*Barrow_top_temperature_data_choice: str = 'air'*)

Bases: object

Barrow_top_temperature_data_choice: str = 'air'

class celestine.params.dimensional.forcing.**DimensionalBackgroundOilHeating**(*oil_mass_ratio: float = 0, ice_type: str = 'FYI'*)

Bases: object

ice_type: str = 'FYI'

oil_mass_ratio: float = 0

class celestine.params.dimensional.forcing.**DimensionalConstantForcing**(*constant_top_temperature: float = -30.32*)

Bases: object

constant_top_temperature: float = -30.32

class celestine.params.dimensional.forcing.**DimensionalConstantLWForcing**(*LW_irradiance: float = 260, ice_emissitivty: float = 0.99, water_emissivity: float = 0.97*)

Bases: object

LW_irradiance: float = 260

ice_emissitivty: float = 0.99

water_emissivity: float = 0.97

class celestine.params.dimensional.forcing.**DimensionalConstantSWForcing**(*SW_irradiance: float = 280, SW_albedo: float = 0.7, SW_penetration_fraction: float = 0.4*)

Bases: object

SW_albedo: float = 0.7

SW_irradiance: float = 280

SW_penetration_fraction: float = 0.4

class celestine.params.dimensional.forcing.**DimensionalConstantTurbulentFlux**(*ref_height: float = 10*, *windspeed: float = 5*, *air_temp: float = 0*, *specific_humidity: float = 0.0036*, *atm_pressure: float = 101.325*, *air_density: float = 1.275*, *air_heat_capacity: float = 1005*, *air_latent_heat_of_vaporisation: float = 2501000.0*)

Bases: object

air_density: float = 1.275

air_heat_capacity: float = 1005

air_latent_heat_of_vaporisation: float = 2501000.0

air_temp: float = 0

atm_pressure: float = 101.325

ref_height: float = 10

specific_humidity: float = 0.0036

windspeed: float = 5

celestine.params.dimensional.forcing.**DimensionalLWForcing**

alias of *DimensionalConstantLWForcing*

class celestine.params.dimensional.forcing.**DimensionalMobileOilHeating**(*ice_type: str = 'FYI'*)

Bases: object

ice_type: str = 'FYI'

class celestine.params.dimensional.forcing.**DimensionalNoHeating**

Bases: object

class celestine.params.dimensional.forcing.**DimensionalRadForcing**(*SW_forcing*: celestine.params.dimensional.forcing.DimensionalCons = *DimensionalConstantSWForcing(SW_irradiance=280, SW_albedo=0.7, SW_penetration_fraction=0.4)*, *LW_forcing*: celestine.params.dimensional.forcing.DimensionalCons = *DimensionalConstantLWForcing(LW_irradiance=260, ice_emissitivty=0.99, water_emissivity=0.97)*, *turbulent_flux*: celestine.params.dimensional.forcing.DimensionalCons = *DimensionalConstantTurbulentFlux(ref_height=10, windspeed=5, air_temp=0, specific_humidity=0.0036, atm_pressure=101.325, air_density=1.275, air_heat_capacity=1005, air_latent_heat_of_vaporisation=2501000.0)*, *oil_heating*: celestine.params.dimensional.forcing.DimensionalBack | celestine.params.dimensional.forcing.DimensionalMob | celestine.params.dimensional.forcing.DimensionalNoH = *DimensionalBackgroundOilHeating(oil_mass_ratio=0, ice_type='FYI')*)

Bases: object

LW_forcing: *DimensionalConstantLWForcing* = **DimensionalConstantLWForcing(LW_irradiance=260, ice_emissitivty=0.99, water_emissivity=0.97)**

SW_forcing: *DimensionalConstantSWForcing* = **DimensionalConstantSWForcing(SW_irradiance=280, SW_albedo=0.7, SW_penetration_fraction=0.4)**

oil_heating: *DimensionalBackgroundOilHeating* | *DimensionalMobileOilHeating* | *DimensionalNoHeating* = **DimensionalBackgroundOilHeating(oil_mass_ratio=0, ice_type='FYI')**

turbulent_flux: *DimensionalConstantTurbulentFlux* = **DimensionalConstantTurbulentFlux(ref_height=10, windspeed=5, air_temp=0, specific_humidity=0.0036, atm_pressure=101.325, air_density=1.275, air_heat_capacity=1005, air_latent_heat_of_vaporisation=2501000.0)**

celestine.params.dimensional.forcing.**DimensionalSWForcing**

alias of *DimensionalConstantSWForcing*

`celestine.params.dimensional.forcing.`**`DimensionalTurbulentFlux`**

alias of *DimensionalConstantTurbulentFlux*

class `celestine.params.dimensional.forcing.`**`DimensionalYearlyForcing`**(*offset: float = -1.0*, *amplitude: float = 0.75*, *period: float = 4.0*)

Bases: `object`

amplitude: float = 0.75

offset: float = -1.0

period: float = 4.0

celestine.params.dimensional.gas module

class `celestine.params.dimensional.gas.`**`DimensionalDISEQGasParams`**(*gas_density: float = 1*, *saturation_concentration: float = 1e-05*, *ocean_saturation_state: float = 1.0*, *gas_diffusivity: float = 0*, *tolerable_super_saturation_fraction: float = 1*, *nucleation_timescale: float = 6869075*)

Bases: *DimensionalEQMGasParams*

nucleation_timescale: float = 6869075

class `celestine.params.dimensional.gas.`**`DimensionalEQMGasParams`**(*gas_density: float = 1*, *saturation_concentration: float = 1e-05*, *ocean_saturation_state: float = 1.0*, *gas_diffusivity: float = 0*, *tolerable_super_saturation_fraction: float = 1*)

Bases: `object`

gas_density: float = 1

gas_diffusivity: float = 0

ocean_saturation_state: float = 1.0

saturation_concentration: float = 1e-05

tolerable_super_saturation_fraction: float = 1

celestine.params.dimensional.initial_conditions module

class celestine.params.dimensional.initial_conditions.**BRW09InitialConditions**(*Barrow_initial_bulk_gas_in_ice: float = 0.2*)

Bases: object

values for bottom (ocean) boundary

Barrow_initial_bulk_gas_in_ice: float = 0.2

class celestine.params.dimensional.initial_conditions.**DimensionalOilInitialConditions**(*initial_ice_depth: float = 1, initial_ocean_temperature: float = -2, initial_ice_temperature: float = -4, initial_oil_volume_fraction: float = 1e-07, initial_ice_bulk_salinity: float = 5.92*)

Bases: object

initial_ice_bulk_salinity: float = 5.92

initial_ice_depth: float = 1

initial_ice_temperature: float = -4

initial_ocean_temperature: float = -2

initial_oil_volume_fraction: float = 1e-07

class celestine.params.dimensional.initial_conditions.**UniformInitialConditions**

Bases: object

values for bottom (ocean) boundary

celestine.params.dimensional.numerical module

class `celestine.params.dimensional.numerical.`**NumericalParams**(*I: int = 50*, *regularisation: float = 1e-06*)

Bases: `object`

parameters needed for discretisation and choice of numerical method

I: int = 50

regularisation: float = 1e-06

property step

celestine.params.dimensional.water module

class `celestine.params.dimensional.water.`**DimensionalWaterParams**(*liquid_density: float = 1028*, *ocean_salinity: float = 34*, *eutectic_salinity: float = 270*, *eutectic_temperature: float = -21.1*, *ocean_temperature: float = -0.81*, *latent_heat: float = 334000.0*, *specific_heat_capacity: float = 4184*, *phase_average_conductivity: bool = False*, *liquid_thermal_conductivity: float = 0.54*, *solid_thermal_conductivity: float = 2.22*, *salt_diffusivity: float = 0*, *liquid_viscosity: float = 0.00278*)

Bases: `object`

property concentration_ratio

Calculate concentration ratio as

$$\mathcal{C} = S_i/\Delta S$$

property conductivity_ratio

Calculate the ratio of solid to liquid thermal conductivity

$$\lambda = \frac{k_s}{k_l}$$

eutectic_salinity: float = 270

eutectic_temperature: float = -21.1

latent_heat: float = 334000.0

property lewis_salt

Calculate the lewis number for salt, return np.inf if there is no salt diffusion.

$$\mathrm{Le}_S = \kappa / D_s$$

liquid_density: float = 1028

liquid_thermal_conductivity: float = 0.54

liquid_viscosity: float = 0.00278

property ocean_freezing_temperature

calculate salinity dependent freezing temperature using liquidus for typical ocean salinity

$$T_i = T_L(S_i) = T_E S_i / S_E$$

ocean_salinity: float = 34

ocean_temperature: float = -0.81

phase_average_conductivity: bool = False

property salinity_difference

calculate difference between eutectic salinity and typical ocean salinity

$$\Delta S = S_E - S_i$$

salt_diffusivity: float = 0

solid_thermal_conductivity: float = 2.22

specific_heat_capacity: float = 4184

property stefan_number

calculate Stefan number

$$\mathrm{St} = L / c_p \Delta T$$

property temperature_difference

calculate

$$\Delta T = T_i - T_E$$

property thermal_diffusivity

Return thermal diffusivity in m2/s

$$\kappa = \frac{k}{\rho_l c_p}$$

Module contents

Submodules

celestine.params.bubble module

`class celestine.params.bubble.BaseBubbleParams`(*B: float = 100*, *pore_throat_scaling: float = 0.46*, *porosity_threshold: bool = False*, *porosity_threshold_value: float = 0.024*, *escape_ice_surface: bool = True*)

Bases: `object`

Not to be used directly but provides parameters for bubble model in sea ice common to other bubble parameter objects.

B: float = 100

escape_ice_surface: bool = True

pore_throat_scaling: float = 0.46

porosity_threshold: bool = False

porosity_threshold_value: float = 0.024

`class celestine.params.bubble.MonoBubbleParams`(*B: float = 100*, *pore_throat_scaling: float = 0.46*, *porosity_threshold: bool = False*, *porosity_threshold_value: float = 0.024*, *escape_ice_surface: bool = True*, *bubble_radius_scaled: float = 1.0*)

Bases: *BaseBubbleParams*

Parameters for population of identical spherical bubbles.

bubble_radius_scaled: float = 1.0

`class celestine.params.bubble.PowerLawBubbleParams`(*B: float = 100*, *pore_throat_scaling: float = 0.46*, *porosity_threshold: bool = False*, *porosity_threshold_value: float = 0.024*, *escape_ice_surface: bool = True*, *bubble_distribution_power: float = 1.5*, *minimum_bubble_radius_scaled: float = 0.001*, *maximum_bubble_radius_scaled: float = 1*)

Bases: *BaseBubbleParams*

Parameters for population of bubbles following a power law size distribution between a minimum and maximum radius.

bubble_distribution_power: float = 1.5

maximum_bubble_radius_scaled: float = 1

minimum_bubble_radius_scaled: float = 0.001

`celestine.params.bubble.get_dimensionless_bubble_params`(*dimensional_params:* DimensionalParams) → *MonoBubbleParams* | *PowerLawBubbleParams*

celestine.params.convection module

class celestine.params.convection.**RJW14Params**(*Rayleigh_salt: float = 44105*, *Rayleigh_critical: float = 2.9*, *convection_strength: float = 0.13*, *couple_bubble_to_horizontal_flow: bool = False*, *couple_bubble_to_vertical_flow: bool = False*)

Bases: `object`

Parameters for the RJW14 parameterisation of brine convection

Rayleigh_critical: float = 2.9

Rayleigh_salt: float = 44105

convection_strength: float = 0.13

couple_bubble_to_horizontal_flow: bool = False

couple_bubble_to_vertical_flow: bool = False

celestine.params.convection.**get_dimensionless_brine_convection_params**(*dimensional_params: DimensionalParams*) → *RJW14Params* | *NoBrineConvection*

celestine.params.convert module

class celestine.params.convert.**Scales**(*lengthscale: float*, *thermal_diffusivity: float*, *liquid_thermal_conductivity: float*, *ocean_salinity: float*, *salinity_difference: float*, *ocean_freezing_temperature: float*, *temperature_difference: float*, *gas_density: float*, *saturation_concentration: float*)

Bases: `object`

convert_dimensional_bulk_air_to_argon_content(*dimensional_bulk_gas*)

Convert kg/m3 of air to micromole of Argon per Liter of ice

convert_from_dimensional_bulk_gas(*dimensional_bulk_gas*)

Non dimensionalise bulk gas content in kg/m3

convert_from_dimensional_bulk_salinity(*dimensional_bulk_salinity*)

Non dimensionalise bulk salinity in g/kg

convert_from_dimensional_dissolved_gas(*dimensional_dissolved_gas*)

convert from dissolved gas in kg(gas)/kg(liquid) to dimensionless

convert_from_dimensional_grid(*dimensional_grid*)

Non dimensionalise domain depths in meters

convert_from_dimensional_heat_flux(*dimensional_heat_flux*)

convert from heat flux in W/m2 to dimensionless units

convert_from_dimensional_heating(*dimensional_heating*)

convert from heating rate in W/m3 to dimensionless units

convert_from_dimensional_temperature(*dimensional_temperature*)
Non dimensionalise temperature in deg C

convert_from_dimensional_time(*dimensional_time*)
Non dimensionalise time in days

convert_to_dimensional_bulk_gas(*bulk_gas*)
Convert dimensionless bulk gas content to kg/m3

convert_to_dimensional_bulk_salinity(*bulk_salinity*)
Convert non dimensional bulk salinity to g/kg

convert_to_dimensional_dissolved_gas(*dissolved_gas*)
convert from non dimensional dissolved gas to dimensional dissolved gas in kg(gas)/kg(liquid)

convert_to_dimensional_grid(*grid*)
Get domain depths in meters from non dimensional values

convert_to_dimensional_temperature(*temperature*)
get temperature in deg C from non dimensional temperature

convert_to_dimensional_time(*time*)
Convert non dimensional time into time in days since start of simulation

gas_density: float

lengthscale: float

liquid_thermal_conductivity: float

ocean_freezing_temperature: float

ocean_salinity: float

salinity_difference: float

saturation_concentration: float

temperature_difference: float

thermal_diffusivity: float

property time_scale
in days

property velocity_scale
in m /day

celestine.params.forcing module

class celestine.params.forcing.**BRW09Forcing**(*ocean_bulk_salinity: float = 0*, *ocean_gas_sat: float = 1.0*, *Barrow_top_temperature_data_choice: str = 'air'*)

Bases: `object`

Surface and ocean temperature data loaded from thermistor temperature record during the Barrow 2009 field study.

Barrow_top_temperature_data_choice: str = 'air'

ocean_bulk_salinity: float = 0

ocean_gas_sat: float = 1.0

class celestine.params.forcing.**BaseOceanForcing**(*ocean_temp: float = 0.1*, *ocean_bulk_salinity: float = 0*, *ocean_gas_sat: float = 1.0*)

Bases: `object`

Not to be used directly but provides parameters for fixed ocean properties: gas saturation, temperature and bulk salinity to other forcing configuration classes

ocean_bulk_salinity: float = 0

ocean_gas_sat: float = 1.0

ocean_temp: float = 0.1

class celestine.params.forcing.**ConstantForcing**(*ocean_temp: float = 0.1*, *ocean_bulk_salinity: float = 0*, *ocean_gas_sat: float = 1.0*, *constant_top_temperature: float = -1.5*)

Bases: *BaseOceanForcing*

Constant temperature forcing

constant_top_temperature: float = -1.5

class celestine.params.forcing.**RadForcing**(*ocean_temp: float = 0.1*, *ocean_bulk_salinity: float = 0*, *ocean_gas_sat: float = 1.0*, *SW_forcing:* DimensionalConstantSWForcing *= DimensionalConstantSWForcing(SW_irradiance=280, SW_albedo=0.7, SW_penetration_fraction=0.4)*, *LW_forcing:* DimensionalConstantLWForcing *= DimensionalConstantLWForcing(LW_irradiance=260, ice_emissitivty=0.99, water_emissivity=0.97)*, *turbulent_flux:* DimensionalConstantTurbulentFlux *= DimensionalConstantTurbulentFlux(ref_height=10, windspeed=5, air_temp=0, specific_humidity=0.0036, atm_pressure=101.325, air_density=1.275, air_heat_capacity=1005, air_latent_heat_of_vaporisation=2501000.0)*, *oil_heating:* DimensionalBackgroundOilHeating | DimensionalMobileOilHeating | DimensionalNoHeating *= DimensionalBackgroundOilHeating(oil_mass_ratio=0, ice_type='FYI')*)

Bases: *BaseOceanForcing*

Forcing parameters for radiative transfer simulation with oil drops

we have not implemented the non-dimensionalisation for these parameters yet and so we just pass the dimensional values directly to the simulation

LW_forcing: *DimensionalConstantLWForcing* **= DimensionalConstantLWForcing(LW_irradiance=260, ice_emissitivty=0.99, water_emissivity=0.97)**

SW_forcing: *DimensionalConstantSWForcing* **= DimensionalConstantSWForcing(SW_irradiance=280, SW_albedo=0.7, SW_penetration_fraction=0.4)**

oil_heating: *DimensionalBackgroundOilHeating* **|** *DimensionalMobileOilHeating* **|** *DimensionalNoHeating* **= DimensionalBackgroundOilHeating(oil_mass_ratio=0, ice_type='FYI')**

turbulent_flux: *DimensionalConstantTurbulentFlux* **= DimensionalConstantTurbulentFlux(ref_height=10, windspeed=5, air_temp=0, specific_humidity=0.0036, atm_pressure=101.325, air_density=1.275, air_heat_capacity=1005, air_latent_heat_of_vaporisation=2501000.0)**

class celestine.params.forcing.**YearlyForcing**(*ocean_temp: float = 0.1*, *ocean_bulk_salinity: float = 0*, *ocean_gas_sat: float = 1.0*, *offset: float = -1.0*, *amplitude: float = 0.75*, *period: float = 4.0*)

Bases: *BaseOceanForcing*

Yearly sinusoidal temperature forcing

amplitude: float = 0.75

offset: float = -1.0

period: float = 4.0

celestine.params.forcing.**get_dimensionless_forcing_config**(*dimensional_params:* DimensionalParams) → *ConstantForcing* | *YearlyForcing* | *BRW09Forcing* | *RadForcing*

celestine.params.initial_conditions module

class celestine.params.initial_conditions.**OilInitialConditions**(*initial_ice_depth: float = 0.5*, *initial_ocean_temperature: float = -0.05*, *initial_ice_temperature: float = -0.1*, *initial_oil_volume_fraction: float = 1e-07*, *initial_ice_bulk_salinity: float = -0.1*)

Bases: object

values for bottom (ocean) boundary

initial_ice_bulk_salinity: float = -0.1

initial_ice_depth: float = 0.5

initial_ice_temperature: float = -0.1

initial_ocean_temperature: float = -0.05

initial_oil_volume_fraction: float = 1e-07

celestine.params.initial_conditions.**get_dimensionless_initial_conditions_config**(*dimensional_params: DimensionalParams*) → *UniformInitialConditions | BRW09InitialConditions | OilInitialConditions*

celestine.params.params module

Classes containing parameters required to run a simulation

The config class contains all the parameters needed to run a simulation as well as methods to save and load this configuration to a yaml file.

class celestine.params.params.**Config**(*name: str*, *total_time: float*, *savefreq: float*, *physical_params: EQMPhysicalParams | DISEQPhysicalParams*, *bubble_params: MonoBubbleParams | PowerLawBubbleParams*, *brine_convection_params: RJW14Params | NoBrineConvection*, *forcing_config: ConstantForcing | YearlyForcing | BRW09Forcing | RadForcing*, *initial_conditions_config: UniformInitialConditions | BRW09InitialConditions | OilInitialConditions*, *numerical_params: NumericalParams = NumericalParams(I=50, regularisation=1e-06)*, *scales: Scales | None = None*)

Bases: `object`

contains all information needed to run a simulation and save output

this config object can be saved and loaded to a yaml file.

brine_convection_params: *RJW14Params | NoBrineConvection*

bubble_params: *MonoBubbleParams | PowerLawBubbleParams*

forcing_config: *ConstantForcing | YearlyForcing | BRW09Forcing | RadForcing*

initial_conditions_config: *UniformInitialConditions | BRW09InitialConditions | OilInitialConditions*

classmethod load(*path*)

name: str

numerical_params: *NumericalParams* = NumericalParams(I=50, regularisation=1e-06)

physical_params: *EQMPhysicalParams | DISEQPhysicalParams*

save(*directory: Path*)

savefreq: float

scales: *Scales* | None = None

total_time: float

celestine.params.params.**get_config**(*dimensional_params:* DimensionalParams) → *Config*

Return a Config object for the simulation.

physical parameters and Darcy law parameters are calculated from the dimensional input. You can modify the numerical parameters and boundary conditions and forcing provided for the simulation.

celestine.params.physical module

class celestine.params.physical.**BasePhysicalParams**(*expansion_coefficient: float = 0.029*, *concentration_ratio: float = 0.17*, *stefan_number: float = 4.2*, *lewis_salt: float = inf*, *lewis_gas: float = inf*, *frame_velocity: float = 0*, *phase_average_conductivity: bool = False*, *conductivity_ratio: float = 4.11*, *tolerable_super_saturation_fraction: float = 1*)

Bases: object

Not to be used directly but provides the common parameters for physical params objects

concentration_ratio: float = 0.17

conductivity_ratio: float = 4.11

expansion_coefficient: float = 0.029

frame_velocity: float = 0

lewis_gas: float = inf

lewis_salt: float = inf

phase_average_conductivity: bool = False

stefan_number: float = 4.2

tolerable_super_saturation_fraction: float = 1

class celestine.params.physical.**DISEQPhysicalParams**(*expansion_coefficient: float = 0.029*, *concentration_ratio: float = 0.17*, *stefan_number: float = 4.2*, *lewis_salt: float = inf*, *lewis_gas: float = inf*, *frame_velocity: float = 0*, *phase_average_conductivity: bool = False*, *conductivity_ratio: float = 4.11*, *tolerable_super_saturation_fraction: float = 1*, *damkohler_number: float = 1*)

Bases: *BasePhysicalParams*

non dimensional numbers for the mushy layer

damkohler_number: float = 1

class celestine.params.physical.**EQMPhysicalParams**(*expansion_coefficient: float = 0.029*, *concentration_ratio: float = 0.17*, *stefan_number: float = 4.2*, *lewis_salt: float = inf*, *lewis_gas: float = inf*, *frame_velocity: float = 0*, *phase_average_conductivity: bool = False*, *conductivity_ratio: float = 4.11*, *tolerable_super_saturation_fraction: float = 1*)

Bases: *BasePhysicalParams*

non dimensional numbers for the mushy layer

`celestine.params.physical.get_dimensionless_physical_params`(*dimensional_params: DimensionalParams*) → *EQMPhysicalParams* | *DISEQPhysicalParams*

return a PhysicalParams object

Module contents

celestine.state package

Submodules

celestine.state.disequilibrium_state module

class `celestine.state.disequilibrium_state.DISEQState`(*time: float*, *enthalpy: ndarray[Any, dtype[_ScalarType_co]]*, *salt: ndarray[Any, dtype[_ScalarType_co]]*, *bulk_dissolved_gas: ndarray[Any, dtype[_ScalarType_co]]*, *gas_fraction: ndarray[Any, dtype[_ScalarType_co]]*)

Bases: `object`

Contains the principal variables for solution with non-equilibrium gas phase. The total bulk gas is partitioned between dissolved gas and free phase gas with a finite nucleation rate (non dimensional damkohler number).

principal solution components: bulk enthalpy bulk salinity bulk dissolved gas gas fraction

all on the center grid.

Note: Define bulk dissolved gas for the system as

expansion_coefficient * liquid_fraction * dissolved_gas

so that this is different from the dissolved gas concentration and

bulk_gas = bulk_dissolved_gas + gas_fraction

in non-dimensional units.

bulk_dissolved_gas: ndarray[Any, dtype[_ScalarType_co]]

enthalpy: ndarray[Any, dtype[_ScalarType_co]]

property gas: ndarray[Any, dtype[_ScalarType_co]]

Calculate bulk gas content and use same attribute name as EQMState

gas_fraction: ndarray[Any, dtype[_ScalarType_co]]

salt: ndarray[Any, dtype[_ScalarType_co]]

time: float

class celestine.state.disequilibrium_state.**DISEQStateBCs**(*time: float*, *enthalpy: ndarray[Any, dtype[_ScalarType_co]]*, *salt: ndarray[Any, dtype[_ScalarType_co]]*, *temperature: ndarray[Any, dtype[_ScalarType_co]]*, *liquid_salinity: ndarray[Any, dtype[_ScalarType_co]]*, *dissolved_gas: ndarray[Any, dtype[_ScalarType_co]]*, *liquid_fraction: ndarray[Any, dtype[_ScalarType_co]]*, *bulk_dissolved_gas: ndarray[Any, dtype[_ScalarType_co]]*, *gas_fraction: ndarray[Any, dtype[_ScalarType_co]]*)

Bases: `object`

Stores information needed for solution at one timestep with BCs on ghost cells as well

Initialiase the prime variables for the solver: enthalpy, bulk salinity and bulk air

bulk_dissolved_gas: ndarray[Any, dtype[_ScalarType_co]]

dissolved_gas: ndarray[Any, dtype[_ScalarType_co]]

enthalpy: ndarray[Any, dtype[_ScalarType_co]]

gas_fraction: ndarray[Any, dtype[_ScalarType_co]]

liquid_fraction: ndarray[Any, dtype[_ScalarType_co]]

liquid_salinity: ndarray[Any, dtype[_ScalarType_co]]

salt: ndarray[Any, dtype[_ScalarType_co]]

temperature: ndarray[Any, dtype[_ScalarType_co]]

time: float

class celestine.state.disequilibrium_state.**DISEQStateFull**(*time: float*, *enthalpy: ndarray[Any, dtype[_ScalarType_co]]*, *salt: ndarray[Any, dtype[_ScalarType_co]]*, *bulk_dissolved_gas: ndarray[Any, dtype[_ScalarType_co]]*, *gas_fraction: ndarray[Any, dtype[_ScalarType_co]]*, *temperature: ndarray[Any, dtype[_ScalarType_co]]*, *liquid_fraction: ndarray[Any, dtype[_ScalarType_co]]*, *solid_fraction: ndarray[Any, dtype[_ScalarType_co]]*, *liquid_salinity: ndarray[Any, dtype[_ScalarType_co]]*, *dissolved_gas: ndarray[Any, dtype[_ScalarType_co]]*)

Bases: `object`

Contains all variables variables for solution with non-equilibrium gas phase after running the enthalpy method on DISEQSate. The total bulk gas is partitioned between dissolved gas and free phase gas with a finite nucleation rate (non dimensional damkohler number).

principal solution components: bulk enthalpy bulk salinity bulk dissolved gas gas fraction

enthalpy method variables: temperature liquid_fraction solid_fraction liquid_salinity dissolved_gas all on the center grid.

Note: Define bulk dissolved gas for the system as

expansion_coefficient * liquid_fraction * dissolved_gas

so that this is different from the dissolved gas concentration and

bulk_gas = bulk_dissolved_gas + gas_fraction

in non-dimensional units.

bulk_dissolved_gas: ndarray[Any, dtype[_ScalarType_co]]

dissolved_gas: ndarray[Any, dtype[_ScalarType_co]]

enthalpy: ndarray[Any, dtype[_ScalarType_co]]

property gas: ndarray[Any, dtype[_ScalarType_co]]

Calculate bulk gas content and use same attribute name as EQMState

gas_fraction: ndarray[Any, dtype[_ScalarType_co]]

liquid_fraction: ndarray[Any, dtype[_ScalarType_co]]

liquid_salinity: ndarray[Any, dtype[_ScalarType_co]]

salt: ndarray[Any, dtype[_ScalarType_co]]

solid_fraction: ndarray[Any, dtype[_ScalarType_co]]

temperature: ndarray[Any, dtype[_ScalarType_co]]

time: float

celestine.state.equilibrium_state module

class celestine.state.equilibrium_state.**EQMState**(*time: float*, *enthalpy: ndarray[Any, dtype[_ScalarType_co]]*, *salt: ndarray[Any, dtype[_ScalarType_co]]*, *gas: ndarray[Any, dtype[_ScalarType_co]]*)

Bases: `object`

Contains the principal variables for solution with equilibrium gas phase:

bulk enthalpy bulk salinity bulk gas

all on the center grid.

enthalpy: ndarray[Any, dtype[_ScalarType_co]]

gas: ndarray[Any, dtype[_ScalarType_co]]

salt: ndarray[Any, dtype[_ScalarType_co]]

time: float

class celestine.state.equilibrium_state.**EQMStateBCs**(*time: float*, *enthalpy: ndarray[Any, dtype[_ScalarType_co]]*, *salt: ndarray[Any, dtype[_ScalarType_co]]*, *gas: ndarray[Any, dtype[_ScalarType_co]]*, *temperature: ndarray[Any, dtype[_ScalarType_co]]*, *liquid_salinity: ndarray[Any, dtype[_ScalarType_co]]*, *dissolved_gas: ndarray[Any, dtype[_ScalarType_co]]*, *gas_fraction: ndarray[Any, dtype[_ScalarType_co]]*, *liquid_fraction: ndarray[Any, dtype[_ScalarType_co]]*)

Bases: `object`

Stores information needed for solution at one timestep with BCs on ghost cells as well

Initialiase the prime variables for the solver: enthalpy, bulk salinity and bulk air

dissolved_gas: ndarray[Any, dtype[_ScalarType_co]]

enthalpy: ndarray[Any, dtype[_ScalarType_co]]

gas: ndarray[Any, dtype[_ScalarType_co]]

gas_fraction: ndarray[Any, dtype[_ScalarType_co]]

liquid_fraction: ndarray[Any, dtype[_ScalarType_co]]

liquid_salinity: ndarray[Any, dtype[_ScalarType_co]]

salt: ndarray[Any, dtype[_ScalarType_co]]

temperature: ndarray[Any, dtype[_ScalarType_co]]

time: float

class celestine.state.equilibrium_state.**EQMStateFull**(*time: float*, *enthalpy: ndarray[Any, dtype[_ScalarType_co]]*, *salt: ndarray[Any, dtype[_ScalarType_co]]*, *gas: ndarray[Any, dtype[_ScalarType_co]]*, *temperature: ndarray[Any, dtype[_ScalarType_co]]*, *liquid_fraction: ndarray[Any, dtype[_ScalarType_co]]*, *solid_fraction: ndarray[Any, dtype[_ScalarType_co]]*, *liquid_salinity: ndarray[Any, dtype[_ScalarType_co]]*, *dissolved_gas: ndarray[Any, dtype[_ScalarType_co]]*, *gas_fraction: ndarray[Any, dtype[_ScalarType_co]]*)

Bases: `object`

Contains all variables variables for solution with equilibrium gas phase after running the enthalpy method on EQMSate.

principal solution components: bulk enthalpy bulk salinity bulk gas

enthalpy method variables: temperature liquid_fraction solid_fraction liquid_salinity dissolved_gas gas_fraction

all on the center grid.

dissolved_gas: ndarray[Any, dtype[_ScalarType_co]]

enthalpy: ndarray[Any, dtype[_ScalarType_co]]

gas: ndarray[Any, dtype[_ScalarType_co]]

gas_fraction: ndarray[Any, dtype[_ScalarType_co]]

liquid_fraction: ndarray[Any, dtype[_ScalarType_co]]

liquid_salinity: ndarray[Any, dtype[_ScalarType_co]]

salt: ndarray[Any, dtype[_ScalarType_co]]

solid_fraction: ndarray[Any, dtype[_ScalarType_co]]

temperature: ndarray[Any, dtype[_ScalarType_co]]

time: float

Module contents

celestine.state.**get_unpacker**(*cfg: Config*) → Callable[[float, ndarray[Any, dtype[_ScalarType_co]]], *EQMState* | *DISEQState*]

1.1.2 Submodules

1.1.3 celestine.example module

Script to run a simulation starting with dimensional parameters and plot output

celestine.example.**create_and_save_config**(*data_directory: Path*, *simulation_dimensional_params: DimensionalParams*)

celestine.example.**main**(*data_directory: Path*, *frames_directory: Path*, *simulation_dimensional_params: DimensionalParams*)

Generate non dimensional simulation config and save along with dimensional config then run simulation and save data.

1.1.4 celestine.grids module

Module providing functions to initialise the different grids and interpolate quantities between them.

class celestine.grids.**Grids**(*number_of_cells: int*)

Bases: object

Class initialised from number of grid cells to contain:

grid cell width, center, edge and ghost grids and difference matrices

property D_e: ndarray[Any, dtype[_ScalarType_co]]

Difference matrix to differentiate edge grid quantities to the center grid

property D_g: ndarray[Any, dtype[_ScalarType_co]]

Difference matrix to differentiate ghost grid quantities to the edge grid

property centers: ndarray[Any, dtype[_ScalarType_co]]
Center grid

property edges: ndarray[Any, dtype[_ScalarType_co]]
Edge grid

property ghosts: ndarray[Any, dtype[_ScalarType_co]]
Ghost grid

number_of_cells: int

property step: float
Grid cell width

celestine.grids.**add_ghost_cells**(*centers*, *bottom*, *top*)

Add specified bottom and top value to center grid

Parameters

- **centers** (*Numpy array*) – numpy array on centered grid (size I).
- **bottom** (*float*) – bottom value placed at index 0.
- **top** (*float*) – top value placed at index -1.

Returns
numpy array on ghost grid (size I+2).

celestine.grids.**calculate_ice_ocean_boundary_depth**(*liquid_fraction*, *edge_grid*)

Calculate the depth of the ice ocean boundary as the edge position of the first cell from the bottom to be not completely liquid. I.e the first time the liquid fraction goes below 1.

If the ice has made it to the bottom of the domain raise an error.

If the domain is completely liquid set h=0.

NOTE: depth is a positive quantity and our grid coordinate increases from -1 at the bottom of the domain to 0 at the top.

Parameters

- **liquid_fraction** (*Numpy Array (size I)*) – liquid fraction on center grid
- **edge_grid** (*Numpy Array (size I+1)*) – The vertical coordinate positions of the edge grid.

Returns
positive depth value of ice ocean interface

celestine.grids.**geometric**(*ghosts*)

Returns geometric mean of the first dimension of an array

celestine.grids.**get_difference_matrix**(*size*, *step*)

celestine.grids.**upwind**(*ghosts*, *velocity*)

1.1.5 celestine.initial_conditions module

Module to provide initial state of bulk enthalpy, bulk salinity and bulk gas for the simulation.

celestine.initial_conditions.**get_initial_conditions**(*cfg: Config*)

1.1.6 celestine.load module

celestine.load.**get_array_data**(*attr: str*, *cfg*, *times*, *data*)

celestine.load.**get_state**(*non_dimensional_time*, *times*, *data*, *cfg*)

celestine.load.**load_data**(*sim_name: str*, *data_directory: Path*, *sim_config_name=None*, *is_dimensional=False*, *config_extension='yml'*)

1.1.7 celestine.oil_simulation module

celestine.oil_simulation.**generate_oil_simulation_config**(*name: str*, *total_time_in_days: float*, *lengthscale: float*, *initial_oil_mass_ratio: float*, *oil_density: float*, *oil_droplet_radius: float*, *SW_irradiance: float*, *SW_albedo: float*, *SW_penetration_fraction: float*, *LW_irradiance: float*, *air_temp: float*, *windspeed: float*, *ref_height: float*, *oil_heating_params: DimensionalBackgroundOilHeating | DimensionalMobileOilHeating | DimensionalNoHeating*, *initial_ice_depth: float*, *initial_ice_temperature: float*, *initial_ocean_temperature: float*, *initial_ice_bulk_salinity: float = 34*, *brine_convection_params: DimensionalRJW14Params | NoBrineConvection = DimensionalRJW14Params(couple_bubble_to_horizontal_flow=False, couple_bubble_to_vertical_flow=False, Rayleigh_critical=2.9, convection_strength=0.13, haline_contraction_coefficient=0.00075, reference_permeability=1e-08)*, *I=50*, *savefreq_in_days=1.0*, *config_directory=PosixPath('.')*) → None

Parameters to generate a simulation config for melting of an initially uniform layer of ice in an ocean under SW, LW radiative fluxes and sensible heat flux.

The latent heat flux is disabled by setting the latent heat of vaporisation to 0.

The initially uniform mass concentration of oil in the domain is set in ng/g.

1.1.8 celestine.printing module

`celestine.printing.`**`get_printer`**(*verbosity_level: int*) → Callable[[str], None]

1.1.9 celestine.run_simulation module

Module to run the simulation on the given configuration with the appropriate solver.

Solve reduced model using scipy solve_ivp using RK23 solver.

Impose a maximum timestep constraint using courant number for thermal diffusion as this is an explicit method.

This solver uses adaptive timestepping which makes it a good choice for running simulations with large buoyancy driven gas bubble velocities and we save the output at intervals given by the savefreq parameter in configuration.

`celestine.run_simulation.`**`run_batch`**(*list_of_cfg: List[Config], directory: Path, verbosity_level=0*) → None

Run a batch of simulations from a list of configurations.

Each simulation name is logged, as well as if it successfully runs or crashes. Output from each simulation is saved in a .npz file.

Parameters

`list_of_cfg` (*`List[celestine.params.Config]`*) – list of configurations

`celestine.run_simulation.`**`solve`**(*cfg: Config, directory: Path, verbosity_level=0*) → Literal[0]

1.1.10 Module contents

CHAPTER TWO

INDICES AND TABLES

- genindex
- modindex
- search

PYTHON MODULE INDEX

C

celestine, 43
celestine.diagnostics, 1
celestine.diagnostics.brine_drainage_parameterisation, 1
celestine.enthalpy_method, 2
celestine.enthalpy_method.common, 1
celestine.enthalpy_method.enthalpy_method, 2
celestine.enthalpy_method.gas, 2
celestine.enthalpy_method.phase_boundaries, 2
celestine.equations, 12
celestine.equations.equations, 11
celestine.equations.flux, 8
celestine.equations.flux.bulk_dissolved_gas_flux, 7
celestine.equations.flux.bulk_gas_flux, 7
celestine.equations.flux.gas_fraction_flux, 7
celestine.equations.flux.heat_flux, 7
celestine.equations.flux.salt_flux, 8
celestine.equations.nucleation, 12
celestine.equations.radiative_heating, 12
celestine.equations.RJW14, 6
celestine.equations.RJW14.brine_channel_sink_terms, 3
celestine.equations.RJW14.brine_drainage, 3
celestine.equations.velocities, 11
celestine.equations.velocities.bubble_parameters, 8
celestine.equations.velocities.mono_distribution, 9
celestine.equations.velocities.power_law_distribution, 9
celestine.equations.velocities.velocities, 10
celestine.example, 40
celestine.forcing, 17
celestine.forcing.boundary_conditions, 16
celestine.forcing.radiative_forcing, 16
celestine.forcing.surface_energy_balance, 16
celestine.forcing.surface_energy_balance.surface_energy_balance, 12
celestine.forcing.surface_energy_balance.turbulent_heat_flux, 14
celestine.forcing.temperature_forcing, 17
celestine.grids, 40
celestine.initial_conditions, 42
celestine.load, 42
celestine.oil_simulation, 42
celestine.params, 36
celestine.params.bubble, 29
celestine.params.convection, 30
celestine.params.convert, 30
celestine.params.dimensional, 29
celestine.params.dimensional.bubble, 17
celestine.params.dimensional.convection, 19
celestine.params.dimensional.dimensional, 19
celestine.params.dimensional.forcing, 22
celestine.params.dimensional.gas, 25
celestine.params.dimensional.initial_conditions, 26
celestine.params.dimensional.numerical, 27
celestine.params.dimensional.water, 27
celestine.params.forcing, 31
celestine.params.initial_conditions, 33
celestine.params.params, 34
celestine.params.physical, 35
celestine.printing, 43
celestine.run_simulation, 43
celestine.state, 40
celestine.state.disequilibrium_state, 36
celestine.state.equilibrium_state, 38

INDEX

A

add_ghost_cells() (*in module celestine.grids*), 41
air_density (*celestine.params.dimensional.forcing.DimensionalConstantTurbulentFlux attribute*), 23
air_heat_capacity (*celestine.params.dimensional.forcing.DimensionalConstantTurbulentFlux attribute*), 23
air_latent_heat_of_vaporisation (*celestine.params.dimensional.forcing.DimensionalConstantTurbulentFlux attribute*), 23
air_temp (*celestine.params.dimensional.forcing.DimensionalConstantTurbulentFlux attribute*), 23
amplitude (*celestine.params.dimensional.forcing.DimensionalYearlyForcing attribute*), 25
amplitude (*celestine.params.forcing.YearlyForcing attribute*), 33
atm_pressure (*celestine.params.dimensional.forcing.DimensionalConstantTurbulentFlux attribute*), 23

B

B (*celestine.params.bubble.BaseBubbleParams attribute*), 29
B (*celestine.params.dimensional.dimensional.DimensionalParams property*), 20
Barrow_initial_bulk_gas_in_ice (*celestine.params.dimensional.initial_conditions.BRW09InitialConditions attribute*), 26
Barrow_top_temperature_data_choice (*celestine.params.dimensional.forcing.DimensionalBRW09Forcing attribute*), 22
Barrow_top_temperature_data_choice (*celestine.params.forcing.BRW09Forcing attribute*), 31
BaseBubbleParams (*class in celestine.params.bubble*), 29
BaseOceanForcing (*class in celestine.params.forcing*), 32
BasePhysicalParams (*class in celestine.params.physical*), 35
brine_convection_params (*celestine.params.dimensional.dimensional.DimensionalParams attribute*), 21
brine_convection_params (*celestine.params.params.Config attribute*), 34
BRW09Forcing (*class in celestine.params.forcing*), 31
BRW09InitialConditions (*class in celestine.params.dimensional.initial_conditions*), 26
bubble_distribution_power (*celestine.params.bubble.PowerLawBubbleParams attribute*), 29
bubble_distribution_power (*celestine.params.dimensional.bubble.DimensionalPowerLawBubblePa attribute*), 18
bubble_params (*celestine.params.dimensional.dimensional.DimensionalParams attribute*), 21
bubble_params (*celestine.params.params.Config attribute*), 34
bubble_radius (*celestine.params.dimensional.bubble.DimensionalMonoBubbleParams attribute*), 18
bubble_radius_scaled (*celestine.params.bubble.MonoBubbleParams attribute*), 29
bubble_radius_scaled (*celestine.params.dimensional.bubble.DimensionalMonoBubbleParams property*), 18
bulk_dissolved_gas (*celestine.state.disequilibrium_state.DISEQState attribute*), 36
bulk_dissolved_gas (*celestine.state.disequilibrium_state.DISEQStateBCs attribute*), 37
bulk_dissolved_gas (*celestine.state.disequilibrium_state.DISEQStateFull attribute*), 38

C

calculate_advective_dissolved_gas_flux() (*in module celestine.equations.flux.bulk_gas_flux*), 7
calculate_advective_heat_flux() (*in module celestine.equations.flux.heat_flux*), 7

calculate_advective_salt_flux() (*in module celestine.equations.flux.salt_flux*), 8
calculate_brine_channel_sink() (*in module celestine.equations.RJW14.brine_drainage*), 3
calculate_brine_channel_strength() (*in module celestine.equations.RJW14.brine_drainage*), 4
calculate_brine_convection_liquid_velocity() (*in module celestine.equations.RJW14.brine_drainage*), 4
calculate_bubble_gas_flux() (*in module celestine.equations.flux.bulk_gas_flux*), 7
calculate_bubble_size_fraction() (*in module celestine.equations.velocities.bubble_parameters*), 8
calculate_bulk_dissolved_gas_flux() (*in module celestine.equations.flux.bulk_dissolved_gas_flux*), 7
calculate_bulk_transfer_coefficient() (*in module celestine.forcing.surface_energy_balance.turbulent_heat_flux*), 14
calculate_common_enthalpy_method_vars() (*in module celestine.enthalpy_method.common*), 1
calculate_conductive_heat_flux() (*in module celestine.equations.flux.heat_flux*), 7
calculate_diffusive_gas_flux() (*in module celestine.equations.flux.bulk_gas_flux*), 7
calculate_diffusive_salt_flux() (*in module celestine.equations.flux.salt_flux*), 8
calculate_DISEQ_dissolved_gas() (*in module celestine.enthalpy_method.gas*), 2
calculate_emissivity() (*in module celestine.forcing.surface_energy_balance.surface_energy_balance*), 12
calculate_EQM_dissolved_gas() (*in module celestine.enthalpy_method.gas*), 2
calculate_EQM_gas_fraction() (*in module celestine.enthalpy_method.gas*), 2
calculate_frame_advection_gas_flux() (*in module celestine.equations.flux.bulk_gas_flux*), 7
calculate_frame_advection_heat_flux() (*in module celestine.equations.flux.heat_flux*), 8
calculate_frame_advection_salt_flux() (*in module celestine.equations.flux.salt_flux*), 8
calculate_frame_velocity() (*in module celestine.equations.velocities.velocities*), 10
calculate_gas_flux() (*in module celestine.equations.flux.bulk_gas_flux*), 7
calculate_gas_fraction_flux() (*in module celestine.equations.flux.gas_fraction_flux*), 7
calculate_gas_interstitial_velocity() (*in module celestine.equations.velocities.velocities*), 10
calculate_heat_flux() (*in module celestine.equations.flux.heat_flux*), 8
calculate_ice_ocean_boundary_depth() (*in module celestine.grids*), 41
calculate_integrated_mean_permeability() (*in module celestine.equations.RJW14.brine_drainage*), 5
calculate_lag_function() (*in module celestine.equations.velocities.mono_distribution*), 9
calculate_lag_integral() (*in module celestine.equations.velocities.power_law_distribution*), 9
calculate_lag_integrand() (*in module celestine.equations.velocities.power_law_distribution*), 9
calculate_latent_heat_flux() (*in module celestine.forcing.surface_energy_balance.turbulent_heat_flux*), 14
calculate_liquid_darcy_velocity() (*in module celestine.equations.velocities.velocities*), 11
calculate_mono_lag_factor() (*in module celestine.equations.velocities.mono_distribution*), 9
calculate_mono_wall_drag_factor() (*in module celestine.equations.velocities.mono_distribution*), 9
calculate_permeability() (*in module celestine.equations.RJW14.brine_drainage*), 5
calculate_power_law_lag_factor() (*in module celestine.equations.velocities.power_law_distribution*), 9
calculate_power_law_wall_drag_factor() (*in module celestine.equations.velocities.power_law_distribution*), 10
calculate_Rayleigh() (*in module celestine.equations.RJW14.brine_drainage*), 3
calculate_ref_air_temp() (*in module celestine.forcing.surface_energy_balance.turbulent_heat_flux*), 15
calculate_ref_atmospheric_pressure() (*in module celestine.forcing.surface_energy_balance.turbulent_heat_flux*), 15
calculate_ref_specific_humidity() (*in module celestine.forcing.surface_energy_balance.turbulent_heat_flux*), 15
calculate_ref_windspeed() (*in module celestine.forcing.surface_energy_balance.turbulent_heat_flux*), 15

calculate_salt_flux() (*in module celestine.equations.flux.salt_flux*), 8
calculate_sensible_heat_flux() (*in module celestine.forcing.surface_energy_balance.turbulent_heat_flux*), 15
calculate_surface_specific_humidity() (*in module celestine.forcing.surface_energy_balance.turbulent_heat_flux*), 16
calculate_total_heat_flux() (*in module celestine.forcing.surface_energy_balance.surface_energy_balance*), 12
calculate_velocities() (*in module celestine.equations.velocities.velocities*), 11
calculate_volume_integrand() (*in module celestine.equations.velocities.power_law_distribution*), 10
calculate_wall_drag_function() (*in module celestine.equations.velocities.mono_distribution*), 9
calculate_wall_drag_integral() (*in module celestine.equations.velocities.power_law_distribution*), 10
calculate_wall_drag_integrand() (*in module celestine.equations.velocities.power_law_distribution*), 10
celestine
    module, 43
celestine.diagnostics
    module, 1
celestine.diagnostics.brine_drainage_parameter
    module, 1
celestine.enthalpy_method
    module, 2
celestine.enthalpy_method.common
    module, 1
celestine.enthalpy_method.enthalpy_method
    module, 2
celestine.enthalpy_method.gas
    module, 2
celestine.enthalpy_method.phase_boundaries
    module, 2
celestine.equations
    module, 12
celestine.equations.equations
    module, 11
celestine.equations.flux
    module, 8
celestine.equations.flux.bulk_dissolved_gas_flux
    module, 7
celestine.equations.flux.bulk_gas_flux
    module, 7
celestine.equations.flux.gas_fraction_flux
    module, 7
celestine.equations.flux.heat_flux
    module, 7
celestine.equations.flux.salt_flux
    module, 8
celestine.equations.nucleation
    module, 12
celestine.equations.radiative_heating
    module, 12
celestine.equations.RJW14
    module, 6
celestine.equations.RJW14.brine_channel_sink_terms
    module, 3
celestine.equations.RJW14.brine_drainage
    module, 3
celestine.equations.velocities
    module, 11
celestine.equations.velocities.bubble_parameters
    module, 8
celestine.equations.velocities.mono_distribution
    module, 9
celestine.equations.velocities.power_law_distribution
    module, 9
celestine.equations.velocities.velocities
    module, 10
celestine.example
    module, 40
celestine.forcing
    module, 17
celestine.forcing.boundary_conditions
    module, 16
celestine.forcing.radiative_forcing
    module, 16
celestine.forcing.surface_energy_balance
    module, 16
celestine.forcing.surface_energy_balance.surface_energy_ba
    module, 12
celestine.forcing.surface_energy_balance.turbulent_heat_fl
    module, 14
celestine.forcing.temperature_forcing
    module, 17
celestine.grids
    module, 40
celestine.initial_conditions
    module, 42
celestine.load
    module, 42
celestine.oil_simulation
    module, 42
celestine.params
    module, 36
celestine.params.bubble
    module, 29
celestine.params.convection
    module, 30

celestine.params.convert
module, 30
celestine.params.dimensional
module, 29
celestine.params.dimensional.bubble
module, 17
celestine.params.dimensional.convection
module, 19
celestine.params.dimensional.dimensional
module, 19
celestine.params.dimensional.forcing
module, 22
celestine.params.dimensional.gas
module, 25
celestine.params.dimensional.initial_conditions
module, 26
celestine.params.dimensional.numerical
module, 27
celestine.params.dimensional.water
module, 27
celestine.params.forcing
module, 31
celestine.params.initial_conditions
module, 33
celestine.params.params
module, 34
celestine.params.physical
module, 35
celestine.printing
module, 43
celestine.run_simulation
module, 43
celestine.state
module, 40
celestine.state.disequilibrium_state
module, 36
celestine.state.equilibrium_state
module, 38
centers (*celestine.grids.Grids property*), 40
concentration_ratio (*celestine.params.dimensional.water.DimensionalWaterParams property*), 27
concentration_ratio (*celestine.params.physical.BasePhysicalParams attribute*), 35
conductivity_ratio (*celestine.params.dimensional.water.DimensionalWaterParams property*), 27
conductivity_ratio (*celestine.params.physical.BasePhysicalParams attribute*), 35
Config (*class in celestine.params.params*), 34
constant_top_temperature (*celestine.params.dimensional.forcing.DimensionalConstantForcing attribute*), 22
constant_top_temperature (*celestine.params.forcing.ConstantForcing attribute*), 32
ConstantForcing (*class in celestine.params.forcing*), 32
convection_strength (*celestine.params.convection.RJW14Params attribute*), 30
convection_strength (*celestine.params.dimensional.convection.DimensionalRJW14Params attribute*), 19
convert_dimensional_bulk_air_to_argon_content() (*celestine.params.convert.Scales method*), 30
convert_from_dimensional_bulk_gas() (*celestine.params.convert.Scales method*), 30
convert_from_dimensional_bulk_salinity() (*celestine.params.convert.Scales method*), 30
convert_from_dimensional_dissolved_gas() (*celestine.params.convert.Scales method*), 30
convert_from_dimensional_grid() (*celestine.params.convert.Scales method*), 30
convert_from_dimensional_heat_flux() (*celestine.params.convert.Scales method*), 30
convert_from_dimensional_heating() (*celestine.params.convert.Scales method*), 30
convert_from_dimensional_temperature() (*celestine.params.convert.Scales method*), 30
convert_from_dimensional_time() (*celestine.params.convert.Scales method*), 31
convert_surface_temperature_to_kelvin() (*in module celestine.forcing.surface_energy_balance.surface_energy_balance*), 13
convert_to_dimensional_bulk_gas() (*celestine.params.convert.Scales method*), 31
convert_to_dimensional_bulk_salinity() (*celestine.params.convert.Scales method*), 31
convert_to_dimensional_dissolved_gas() (*celestine.params.convert.Scales method*), 31
convert_to_dimensional_grid() (*celestine.params.convert.Scales method*), 31
convert_to_dimensional_temperature() (*celestine.params.convert.Scales method*), 31
convert_to_dimensional_time() (*celestine.params.convert.Scales method*), 31
couple_bubble_to_horizontal_flow (*celestine.params.convection.RJW14Params attribute*), 30
couple_bubble_to_horizontal_flow (*celestine.params.dimensional.convection.DimensionalRJW14Params attribute*), 19
couple_bubble_to_vertical_flow (*celestine.params.convection.RJW14Params at-*

tribute), 30
couple_bubble_to_vertical_flow (*celestine.params.dimensional.convection.DimensionalRJW14Params attribute*), 19
create_and_save_config() (*in module celestine.example*), 40

D

D_e (*celestine.grids.Grids property*), 40
D_g (*celestine.grids.Grids property*), 40
damkohler_number (*celestine.params.dimensional.dimensional.DimensionalParams property*), 21
damkohler_number (*celestine.params.physical.DISEQPhysicalParams attribute*), 35
DimensionalBackgroundOilHeating (*class in celestine.params.dimensional.forcing*), 22
DimensionalBaseBubbleParams (*class in celestine.params.dimensional.bubble*), 17
DimensionalBRW09Forcing (*class in celestine.params.dimensional.forcing*), 22
DimensionalConstantForcing (*class in celestine.params.dimensional.forcing*), 22
DimensionalConstantLWForcing (*class in celestine.params.dimensional.forcing*), 22
DimensionalConstantSWForcing (*class in celestine.params.dimensional.forcing*), 22
DimensionalConstantTurbulentFlux (*class in celestine.params.dimensional.forcing*), 23
DimensionalDISEQGasParams (*class in celestine.params.dimensional.gas*), 25
DimensionalEQMGasParams (*class in celestine.params.dimensional.gas*), 25
DimensionalLWForcing (*in module celestine.params.dimensional.forcing*), 23
DimensionalMobileOilHeating (*class in celestine.params.dimensional.forcing*), 23
DimensionalMonoBubbleParams (*class in celestine.params.dimensional.bubble*), 17
DimensionalNoHeating (*class in celestine.params.dimensional.forcing*), 23
DimensionalOilInitialConditions (*class in celestine.params.dimensional.initial_conditions*), 26
DimensionalParams (*class in celestine.params.dimensional.dimensional*), 19
DimensionalPowerLawBubbleParams (*class in celestine.params.dimensional.bubble*), 18
DimensionalRadForcing (*class in celestine.params.dimensional.forcing*), 23
DimensionalRJW14Params (*class in celestine.params.dimensional.convection*), 19
DimensionalSWForcing (*in module celestine.params.dimensional.forcing*), 24
DimensionalTurbulentFlux (*in module celestine.params.dimensional.forcing*), 24
DimensionalWaterParams (*class in celestine.params.dimensional.water*), 27
DimensionalYearlyForcing (*class in celestine.params.dimensional.forcing*), 25
DISEQPhysicalParams (*class in celestine.params.physical*), 35
DISEQState (*class in celestine.state.disequilibrium_state*), 36
DISEQStateBCs (*class in celestine.state.disequilibrium_state*), 36
DISEQStateFull (*class in celestine.state.disequilibrium_state*), 37
dissolved_gas (*celestine.state.disequilibrium_state.DISEQStateBCs attribute*), 37
dissolved_gas (*celestine.state.disequilibrium_state.DISEQStateFull attribute*), 38
dissolved_gas (*celestine.state.equilibrium_state.EQMStateBCs attribute*), 39
dissolved_gas (*celestine.state.equilibrium_state.EQMStateFull attribute*), 39

E

edges (*celestine.grids.Grids property*), 41
enthalpy (*celestine.state.disequilibrium_state.DISEQState attribute*), 36
enthalpy (*celestine.state.disequilibrium_state.DISEQStateBCs attribute*), 37
enthalpy (*celestine.state.disequilibrium_state.DISEQStateFull attribute*), 38
enthalpy (*celestine.state.equilibrium_state.EQMState attribute*), 38
enthalpy (*celestine.state.equilibrium_state.EQMStateBCs attribute*), 39
enthalpy (*celestine.state.equilibrium_state.EQMStateFull attribute*), 40
EQMPhysicalParams (*class in celestine.params.physical*), 35
EQMState (*class in celestine.state.equilibrium_state*), 38
EQMStateBCs (*class in celestine.state.equilibrium_state*), 38
EQMStateFull (*class in celestine.state.equilibrium_state*), 39
escape_ice_surface (*celestine.params.bubble.BaseBubbleParams attribute*), 29
escape_ice_surface (*celestine.params.dimensional.bubble.DimensionalBaseBubbleParams attribute*), 17

eutectic_salinity (*celestine.params.dimensional.water.DimensionalWaterParams attribute*), 27
eutectic_temperature (*celestine.params.dimensional.water.DimensionalWaterParams attribute*), 27
expansion_coefficient (*celestine.params.dimensional.dimensional.DimensionalParams property*), 21
expansion_coefficient (*celestine.params.physical.BasePhysicalParams attribute*), 35

F

find_ghost_cell_temperature() (*in module celestine.forcing.surface_energy_balance.surface_energy_balance*), 13
forcing_config (*celestine.params.dimensional.dimensional.DimensionalParams attribute*), 21
forcing_config (*celestine.params.params.Config attribute*), 34
frame_velocity (*celestine.params.dimensional.dimensional.DimensionalParams property*), 21
frame_velocity (*celestine.params.physical.BasePhysicalParams attribute*), 35
frame_velocity_dimensional (*celestine.params.dimensional.dimensional.DimensionalParams attribute*), 21

G

gas (*celestine.state.disequilibrium_state.DISEQState property*), 36
gas (*celestine.state.disequilibrium_state.DISEQStateFull property*), 38
gas (*celestine.state.equilibrium_state.EQMState attribute*), 38
gas (*celestine.state.equilibrium_state.EQMStateBCs attribute*), 39
gas (*celestine.state.equilibrium_state.EQMStateFull attribute*), 40
gas_density (*celestine.params.convert.Scales attribute*), 31
gas_density (*celestine.params.dimensional.gas.DimensionalEQMGasParams attribute*), 25
gas_diffusivity (*celestine.params.dimensional.gas.DimensionalEQMGasParams attribute*), 25
gas_fraction (*celestine.state.disequilibrium_state.DISEQState attribute*), 36
gas_fraction (*celestine.state.disequilibrium_state.DISEQStateBCs attribute*), 37
gas_fraction (*celestine.state.disequilibrium_state.DISEQStateFull attribute*), 38
gas_fraction (*celestine.state.equilibrium_state.EQMStateBCs attribute*), 39
gas_fraction (*celestine.state.equilibrium_state.EQMStateFull attribute*), 40
gas_params (*celestine.params.dimensional.dimensional.DimensionalParar attribute*), 21
generate_oil_simulation_config() (*in module celestine.oil_simulation*), 42
geometric() (*in module celestine.grids*), 41
get_array_data() (*in module celestine.load*), 42
get_bottom_temperature_forcing() (*in module celestine.forcing.temperature_forcing*), 17
get_boundary_conditions() (*in module celestine.forcing.boundary_conditions*), 16
get_brine_convection_sink() (*in module celestine.equations.RJW14.brine_channel_sink_terms*), 3
get_config() (*in module celestine.params.params*), 34
get_convecting_region_height() (*in module celestine.equations.RJW14.brine_drainage*), 5
get_difference_matrix() (*in module celestine.grids*), 41
get_dimensionless_brine_convection_params() (*in module celestine.params.convection*), 30
get_dimensionless_bubble_params() (*in module celestine.params.bubble*), 29
get_dimensionless_forcing_config() (*in module celestine.params.forcing*), 33
get_dimensionless_initial_conditions_config() (*in module celestine.params.initial_conditions*), 33
get_dimensionless_physical_params() (*in module celestine.params.physical*), 36
get_dz_fluxes() (*in module celestine.equations.flux*), 8
get_effective_Rayleigh_number() (*in module celestine.equations.RJW14.brine_drainage*), 6
get_enthalpy_method() (*in module celestine.enthalpy_method.enthalpy_method*), 2
get_equations() (*in module celestine.equations.equations*), 11
get_initial_conditions() (*in module celestine.initial_conditions*), 42
get_LW_forcing() (*in module celestine.forcing.radiative_forcing*), 16
get_nucleation() (*in module celestine.equations.nucleation*), 12
get_phase_masks() (*in module celestine.enthalpy_method.phase_boundaries*), 2
get_printer() (*in module celestine.printing*), 43

get_radiative_heating() (*in module celestine.equations.radiative_heating*), 12
get_state() (*in module celestine.load*), 42
get_SW_forcing() (*in module celestine.forcing.radiative_forcing*), 16
get_temperature_forcing() (*in module celestine.forcing.temperature_forcing*), 17
get_unpacker() (*in module celestine.state*), 40
ghosts (*celestine.grids.Grids property*), 41
gravity (*celestine.params.dimensional.dimensional.DimensionalParams attribute*), 21
Grids (*class in celestine.grids*), 40

H

haline_contraction_coefficient (*celestine.params.dimensional.convection.DimensionalRJW14Params attribute*), 19

I

I (*celestine.params.dimensional.numerical.NumericalParams attribute*), 27
ice_emissivtiy (*celestine.params.dimensional.forcing.DimensionalConstantLWForcing attribute*), 22
ice_type (*celestine.params.dimensional.forcing.DimensionalBackgroundOilHeating attribute*), 22
ice_type (*celestine.params.dimensional.forcing.DimensionalMobileOilHeating attribute*), 23
initial_conditions_config (*celestine.params.dimensional.dimensional.DimensionalParams attribute*), 21
initial_conditions_config (*celestine.params.params.Config attribute*), 34
initial_ice_bulk_salinity (*celestine.params.dimensional.initial_conditions.DimensionalOilInitialConditions attribute*), 26
initial_ice_bulk_salinity (*celestine.params.initial_conditions.OilInitialConditions attribute*), 33
initial_ice_depth (*celestine.params.dimensional.initial_conditions.DimensionalOilInitialConditions attribute*), 26
initial_ice_depth (*celestine.params.initial_conditions.OilInitialConditions attribute*), 33
initial_ice_temperature (*celestine.params.dimensional.initial_conditions.DimensionalOilInitialConditions attribute*), 26
initial_ice_temperature (*celestine.params.initial_conditions.OilInitialConditions attribute*), 33
initial_ocean_temperature (*celestine.params.dimensional.initial_conditions.DimensionalOilInitialConditions attribute*), 26
initial_ocean_temperature (*celestine.params.initial_conditions.OilInitialConditions attribute*), 33
initial_oil_volume_fraction (*celestine.params.dimensional.initial_conditions.DimensionalOilInitialConditions attribute*), 26
initial_oil_volume_fraction (*celestine.params.initial_conditions.OilInitialConditions attribute*), 33

L

latent_heat (*celestine.params.dimensional.water.DimensionalWaterParams attribute*), 27
lengthscale (*celestine.params.convert.Scales attribute*), 31
lengthscale (*celestine.params.dimensional.dimensional.DimensionalParams attribute*), 21
lewis_gas (*celestine.params.dimensional.dimensional.DimensionalParams property*), 21
lewis_gas (*celestine.params.physical.BasePhysicalParams attribute*), 35
lewis_salt (*celestine.params.dimensional.water.DimensionalWaterParams property*), 27
lewis_salt (*celestine.params.physical.BasePhysicalParams attribute*), 35
liquid_density (*celestine.params.dimensional.water.DimensionalWaterParams attribute*), 28
liquid_fraction (*celestine.state.disequilibrium_state.DISEQStateBCs attribute*), 37
liquid_fraction (*celestine.state.disequilibrium_state.DISEQStateFull attribute*), 38
liquid_fraction (*celestine.state.equilibrium_state.EQMStateBCs attribute*), 39
liquid_fraction (*celestine.state.equilibrium_state.EQMStateFull attribute*), 40
liquid_salinity (*celestine.state.disequilibrium_state.DISEQStateBCs attribute*), 37
liquid_salinity (*celestine.state.disequilibrium_state.DISEQStateFull attribute*), 38
liquid_salinity (*celestine.state.equilibrium_state.EQMStateBCs attribute*), 39
liquid_salinity (*celestine.state.equilibrium_state.EQMStateFull attribute*), 40
liquid_thermal_conductivity (*celestine.params.convert.Scales attribute*), 31

liquid_thermal_conductivity (*celestine.params.dimensional.water.DimensionalWaterParams attribute*), 28
liquid_viscosity (*celestine.params.dimensional.water.DimensionalWaterParams attribute*), 28
load() (*celestine.params.dimensional.dimensional.DimensionalParams class method*), 21
load() (*celestine.params.params.Config class method*), 34
load_data() (*in module celestine.load*), 42
LW_forcing (*celestine.params.dimensional.forcing.DimensionalRadForcing attribute*), 24
LW_forcing (*celestine.params.forcing.RadForcing attribute*), 32
LW_irradiance (*celestine.params.dimensional.forcing.DimensionalConstantLWForcing attribute*), 22

M

main() (*in module celestine.diagnostics.brine_drainage_parameterisation*), 1
main() (*in module celestine.example*), 40
maximum_bubble_radius (*celestine.params.dimensional.bubble.DimensionalPowerLawBubbleParams attribute*), 18
maximum_bubble_radius_scaled (*celestine.params.bubble.PowerLawBubbleParams attribute*), 29
maximum_bubble_radius_scaled (*celestine.params.dimensional.bubble.DimensionalPowerLawBubbleParams property*), 18
minimum_bubble_radius (*celestine.params.dimensional.bubble.DimensionalPowerLawBubbleParams attribute*), 18
minimum_bubble_radius_scaled (*celestine.params.bubble.PowerLawBubbleParams attribute*), 29
minimum_bubble_radius_scaled (*celestine.params.dimensional.bubble.DimensionalPowerLawBubbleParams property*), 18
module
  celestine, 43
  celestine.diagnostics, 1
  celestine.diagnostics.brine_drainage_parameterisation, 1
  celestine.enthalpy_method, 2
  celestine.enthalpy_method.common, 1
  celestine.enthalpy_method.enthalpy_method, 2
  celestine.enthalpy_method.gas, 2
  celestine.enthalpy_method.phase_boundaries, 2
  celestine.equations, 12
  celestine.equations.equations, 11
  celestine.equations.flux, 8
  celestine.equations.flux.bulk_dissolved_gas_flux, 7
  celestine.equations.flux.bulk_gas_flux, 7
  celestine.equations.flux.gas_fraction_flux, 7
  celestine.equations.flux.heat_flux, 7
  celestine.equations.flux.salt_flux, 8
  celestine.equations.nucleation, 12
  celestine.equations.radiative_heating, 12
  celestine.equations.RJW14, 6
  celestine.equations.RJW14.brine_channel_sink_terms, 3
  celestine.equations.RJW14.brine_drainage, 3
  celestine.equations.velocities, 11
  celestine.equations.velocities.bubble_parameters, 8
  celestine.equations.velocities.mono_distribution, 9
  celestine.equations.velocities.power_law_distribution, 9
  celestine.equations.velocities.velocities, 10
  celestine.example, 40
  celestine.forcing, 17
  celestine.forcing.boundary_conditions, 16
  celestine.forcing.radiative_forcing, 16
  celestine.forcing.surface_energy_balance, 16
  celestine.forcing.surface_energy_balance.surface_energ 12
  celestine.forcing.surface_energy_balance.turbulent_hea 14
  celestine.forcing.temperature_forcing, 17
  celestine.grids, 40
  celestine.initial_conditions, 42
  celestine.load, 42
  celestine.oil_simulation, 42
  celestine.params, 36
  celestine.params.bubble, 29
  celestine.params.convection, 30
  celestine.params.convert, 30
  celestine.params.dimensional, 29
  celestine.params.dimensional.bubble, 17
  celestine.params.dimensional.convection, 19
  celestine.params.dimensional.dimensional, 19
  celestine.params.dimensional.forcing, 22
  celestine.params.dimensional.gas, 25

celestine.params.dimensional.initial_conditions, 26
celestine.params.dimensional.numerical, 27
celestine.params.dimensional.water, 27
celestine.params.forcing, 31
celestine.params.initial_conditions, 33
celestine.params.params, 34
celestine.params.physical, 35
celestine.printing, 43
celestine.run_simulation, 43
celestine.state, 40
celestine.state.disequilibrium_state, 36
celestine.state.equilibrium_state, 38

MonoBubbleParams (*class in celestine.params.bubble*), 29

N

name (*celestine.params.dimensional.dimensional.DimensionalParams attribute*), 21

name (*celestine.params.params.Config attribute*), 34

NoBrineConvection (*class in celestine.params.dimensional.convection*), 19

nucleation_timescale (*celestine.params.dimensional.gas.DimensionalDISEQGasParams attribute*), 25

number_of_cells (*celestine.grids.Grids attribute*), 41

numerical_params (*celestine.params.dimensional.dimensional.DimensionalParams attribute*), 21

numerical_params (*celestine.params.params.Config attribute*), 34

NumericalParams (*class in celestine.params.dimensional.numerical*), 27

O

ocean_bulk_salinity (*celestine.params.forcing.BaseOceanForcing attribute*), 32

ocean_bulk_salinity (*celestine.params.forcing.BRW09Forcing attribute*), 32

ocean_freezing_temperature (*celestine.params.convert.Scales attribute*), 31

ocean_freezing_temperature (*celestine.params.dimensional.water.DimensionalWaterParams property*), 28

ocean_gas_sat (*celestine.params.forcing.BaseOceanForcing attribute*), 32

ocean_gas_sat (*celestine.params.forcing.BRW09Forcing attribute*), 32

ocean_salinity (*celestine.params.convert.Scales attribute*), 31

ocean_salinity (*celestine.params.dimensional.water.DimensionalWaterParams attribute*), 28

ocean_saturation_state (*celestine.params.dimensional.gas.DimensionalEQMGasParams attribute*), 25

ocean_temp (*celestine.params.forcing.BaseOceanForcing attribute*), 32

ocean_temperature (*celestine.params.dimensional.water.DimensionalWaterParams attribute*), 28

offset (*celestine.params.dimensional.forcing.DimensionalYearlyForcing attribute*), 25

offset (*celestine.params.forcing.YearlyForcing attribute*), 33

oil_heating (*celestine.params.dimensional.forcing.DimensionalRadForci attribute*), 24

oil_heating (*celestine.params.forcing.RadForcing attribute*), 33

oil_mass_ratio (*celestine.params.dimensional.forcing.DimensionalBackgroundOilHeat attribute*), 22

OilInitialConditions (*class in celestine.params.initial_conditions*), 33

P

period (*celestine.params.dimensional.forcing.DimensionalYearlyForcing attribute*), 25

period (*celestine.params.forcing.YearlyForcing attribute*), 33

phase_average_conductivity (*celestine.params.dimensional.water.DimensionalWaterParams attribute*), 28

phase_average_conductivity (*celestine.params.physical.BasePhysicalParams attribute*), 35

physical_params (*celestine.params.params.Config attribute*), 34

pore_radius (*celestine.params.dimensional.bubble.DimensionalBaseBubl attribute*), 17

pore_throat_scaling (*celestine.params.bubble.BaseBubbleParams attribute*), 29

pore_throat_scaling (*celestine.params.dimensional.bubble.DimensionalBaseBubbleParams attribute*), 17

porosity_threshold (*celestine.params.bubble.BaseBubbleParams attribute*), 29

porosity_threshold (*celestine.params.dimensional.bubble.DimensionalBaseBubbleParams attribute*), 17

porosity_threshold_value (celestine.params.bubble.BaseBubbleParams attribute), 29
porosity_threshold_value (celestine.params.dimensional.bubble.DimensionalBaseBubbleParams attribute), 17
PowerLawBubbleParams (class in celestine.params.bubble), 29

R

RadForcing (class in celestine.params.forcing), 32
Rayleigh_critical (celestine.params.convection.RJW14Params attribute), 30
Rayleigh_critical (celestine.params.dimensional.convection.DimensionalRJW14Params attribute), 19
Rayleigh_salt (celestine.params.convection.RJW14Params attribute), 30
Rayleigh_salt (celestine.params.dimensional.dimensional.DimensionalParams property), 20
ref_height (celestine.params.dimensional.forcing.DimensionalConstantTurbulentFlux attribute), 23
reference_permeability (celestine.params.dimensional.convection.DimensionalRJW14Params attribute), 19
regularisation (celestine.params.dimensional.numerical.NumericalParams attribute), 27
RJW14Params (class in celestine.params.convection), 30
run_batch() (in module celestine.run_simulation), 43

S

salinity_difference (celestine.params.convert.Scales attribute), 31
salinity_difference (celestine.params.dimensional.water.DimensionalWaterParams property), 28
salt (celestine.state.disequilibrium_state.DISEQState attribute), 36
salt (celestine.state.disequilibrium_state.DISEQStateBCs attribute), 37
salt (celestine.state.disequilibrium_state.DISEQStateFull attribute), 38
salt (celestine.state.equilibrium_state.EQMState attribute), 38
salt (celestine.state.equilibrium_state.EQMStateBCs attribute), 39
salt (celestine.state.equilibrium_state.EQMStateFull attribute), 40
salt_diffusivity (celestine.params.dimensional.water.DimensionalWaterParams attribute), 28
saturation_concentration (celestine.params.convert.Scales attribute), 31
saturation_concentration (celestine.params.dimensional.gas.DimensionalEQMGasParams attribute), 25
save() (celestine.params.dimensional.dimensional.DimensionalParams method), 21
save() (celestine.params.params.Config method), 34
savefreq (celestine.params.dimensional.dimensional.DimensionalParams property), 21
savefreq (celestine.params.params.Config attribute), 34
savefreq_in_days (celestine.params.dimensional.dimensional.DimensionalParams attribute), 21
scales (celestine.params.dimensional.dimensional.DimensionalParams property), 22
scales (celestine.params.params.Config attribute), 34
Scales (class in celestine.params.convert), 30
solid_fraction (celestine.state.disequilibrium_state.DISEQStateFull attribute), 38
solid_fraction (celestine.state.equilibrium_state.EQMStateFull attribute), 40
solid_thermal_conductivity (celestine.params.dimensional.water.DimensionalWaterParams attribute), 28
solve() (in module celestine.run_simulation), 43
solve_for_surface_temp() (in module celestine.forcing.surface_energy_balance.surface_energy_balance), 13
specific_heat_capacity (celestine.params.dimensional.water.DimensionalWaterParams attribute), 28
specific_humidity (celestine.params.dimensional.forcing.DimensionalConstantTurbulentF attribute), 23
stefan_number (celestine.params.dimensional.water.DimensionalWaterParams property), 28
stefan_number (celestine.params.physical.BasePhysicalParams attribute), 35
step (celestine.grids.Grids property), 41
step (celestine.params.dimensional.numerical.NumericalParams property), 27
surface_temp_gradient() (in module celestine.forcing.surface_energy_balance.surface_energy_balance), 13
SW_albedo (celestine.params.dimensional.forcing.DimensionalConstantSW attribute), 23
SW_forcing (celestine.params.dimensional.forcing.DimensionalRadForcin attribute), 24

SW_forcing (*celestine.params.forcing.RadForcing attribute*), 32
SW_irradiance (*celestine.params.dimensional.forcing.DimensionalConstantSWForcing attribute*), 23
SW_penetration_fraction (*celestine.params.dimensional.forcing.DimensionalConstantSWForcing attribute*), 23

T

temperature (*celestine.state.disequilibrium_state.DISEQStateBCs attribute*), 37
temperature (*celestine.state.disequilibrium_state.DISEQStateFull attribute*), 38
temperature (*celestine.state.equilibrium_state.EQMStateBCs attribute*), 39
temperature (*celestine.state.equilibrium_state.EQMStateFull attribute*), 40
temperature_difference (*celestine.params.convert.Scales attribute*), 31
temperature_difference (*celestine.params.dimensional.water.DimensionalWaterParams property*), 28
thermal_diffusivity (*celestine.params.convert.Scales attribute*), 31
thermal_diffusivity (*celestine.params.dimensional.water.DimensionalWaterParams property*), 28
time (*celestine.state.disequilibrium_state.DISEQState attribute*), 36
time (*celestine.state.disequilibrium_state.DISEQStateBCs attribute*), 37
time (*celestine.state.disequilibrium_state.DISEQStateFull attribute*), 38
time (*celestine.state.equilibrium_state.EQMState attribute*), 38
time (*celestine.state.equilibrium_state.EQMStateBCs attribute*), 39
time (*celestine.state.equilibrium_state.EQMStateFull attribute*), 40
time_scale (*celestine.params.convert.Scales property*), 31
tolerable_super_saturation_fraction (*celestine.params.dimensional.gas.DimensionalEQMGasParams attribute*), 25
tolerable_super_saturation_fraction (*celestine.params.physical.BasePhysicalParams attribute*), 35
top_cell_conductivity() (*in module celestine.forcing.surface_energy_balance.surface_energy_balance*), 14
total_time (*celestine.params.dimensional.dimensional.DimensionalParams property*), 22
total_time (*celestine.params.params.Config attribute*), 34
total_time_in_days (*celestine.params.dimensional.dimensional.DimensionalParams attribute*), 22
turbulent_flux (*celestine.params.dimensional.forcing.DimensionalRadForcing attribute*), 24
turbulent_flux (*celestine.params.forcing.RadForcing attribute*), 33

U

UniformInitialConditions (*class in celestine.params.dimensional.initial_conditions*), 26
upwind() (*in module celestine.grids*), 41

V

velocity_scale (*celestine.params.convert.Scales property*), 31

W

water_emissivity (*celestine.params.dimensional.forcing.DimensionalConstantLWForcing attribute*), 22
water_params (*celestine.params.dimensional.dimensional.DimensionalPa attribute*), 22
windspeed (*celestine.params.dimensional.forcing.DimensionalConstantTu attribute*), 23

Y

YearlyForcing (*class in celestine.params.forcing*), 33