# EMPIRE DA

0.1

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# **Contents**

1	EMP	PIRE Dat	ta Assimil	lati	ion	Do	cun	ner	ntat	ion	1													1
	1.1	Downlo	oading															 						1
	1.2	Compi	ling															 						1
		1.2.1	Compilat	tior	า of	the	sou	urce	e cc	ode								 						1
		1.2.2	Compilat	tior	า of	the	dod	cun	nen	tati	on							 						2
	1.3	Custon	nising for s	spe	ecifi	ic m	ode	els .										 						2
	1.4	Testing																 						3
	1.5	Linking	to your m	100	lel ı	usin	g El	MP	'IRE									 						3
	1.6	Runnir	ng															 						3
	1.7	Examp	les															 						3
	1.8	Bug Re	eports and	d F	unc	tion	ality	y Re	equ	est	s .							 						4
2	Data	Type Ir	ndex																					5
	2.1	Data T	ypes List															 						5
3	File	Index																						7
	3.1	File Lis	st															 						7
4	Data	Type D	ocument	ati	on																			9
	4.1	comms	Module F	₹ef	ere	nce												 						9
		4.1.1	Detailed	De	escr	riptic	on											 						9
		4.1.2	Member	Fu	ınct	ion/	Sub	orol	utino	e D	ocı	ume	enta	atio	n			 						10
			4.1.2.1	а	ılloc	cate_	_da	ıta .										 						10
			4.1.2.2	d	leal	lloca	ıte_	dat	ta									 						10
			4.1.2.3	ir	nitia	alise	_mp	pi .										 						10
		4.1.3	Member	Da	ata	Doc	ume	ent	atio	n .								 						10
			4.1.3.1	С	pl_	mpi_	_co	mn	n.									 						10
			4.1.3.2	g	Jblc	ount	t .											 						10
			4.1.3.3	g	Jbld	lisp												 						11
			4.1.3.4	n	пур	e_id	<u>.</u>											 						11
			4.1.3.5	n	nyra	ank												 						11
			4.1.3.6	n	ıpfs													 						11

iv CONTENTS

		4.1.3.7	nproc	. 11
		4.1.3.8	pf_mpi_comm	. 11
		4.1.3.9	pfrank	. 11
4.2	histogr	am_data N	Module Reference	. 11
	4.2.1	Detailed	Description	. 12
	4.2.2	Member	Function/Subroutine Documentation	. 12
		4.2.2.1	kill_histogram_data	. 12
		4.2.2.2	load_histogram_data	. 12
	4.2.3	Member	Data Documentation	. 12
		4.2.3.1	rank_hist_list	. 12
		4.2.3.2	rank_hist_nums	. 12
		4.2.3.3	rhl_n	. 12
		4.2.3.4	rhn_n	. 12
4.3	hqht_p	lus_r Mod	lule Reference	. 13
	4.3.1	Detailed	Description	. 13
	4.3.2	Member	Function/Subroutine Documentation	. 13
		4.3.2.1	hqhtr_factor	. 13
		4.3.2.2	kill_hqhtr	. 13
		4.3.2.3	load_hqhtr	. 13
4.4	pf_con	trol Modul	le Reference	. 14
	4.4.1	Detailed	Description	. 14
	4.4.2	Member	Function/Subroutine Documentation	. 15
		4.4.2.1	allocate_pf	. 15
		4.4.2.2	deallocate_pf	. 15
		4.4.2.3	parse_pf_parameters	. 15
		4.4.2.4	set_pf_controls	. 16
	4.4.3	Member	Data Documentation	. 17
		4.4.3.1	pf	. 17
4.5	pf_con	trol::pf_co	ntrol_type Type Reference	. 17
	4.5.1	Detailed	Description	. 19
	4.5.2	Member	Data Documentation	. 19
		4.5.2.1	count	. 19
		4.5.2.2	couple_root	. 19
		4.5.2.3	efac	. 19
		4.5.2.4	gen_data	. 19
		4.5.2.5	gen_q	. 19
		4.5.2.6	human_readable	. 19
		4.5.2.7	init	. 20
		4.5.2.8	keep	. 20
		4.5.2.9	len	. 20

CONTENTS

		4.5.2.10	mean	20
		4.5.2.11	nens	20
		4.5.2.12	nfac	20
		4.5.2.13	nudgefac	20
		4.5.2.14	particles	20
		4.5.2.15	psi	21
		4.5.2.16	qscale	21
		4.5.2.17	rho	21
		4.5.2.18	talagrand	21
		4.5.2.19	time	21
		4.5.2.20	time_bwn_obs	21
		4.5.2.21	time_obs	21
		4.5.2.22	timestep	21
		4.5.2.23	type	21
		4.5.2.24	ufac	22
		4.5.2.25	use_mean	22
		4.5.2.26	use_rmse	22
		4.5.2.27	use_talagrand	22
		4.5.2.28	use_traj	22
		4.5.2.29	use_var	22
		4.5.2.30	use_weak	22
		4.5.2.31	weight	22
4.6	qdata I	Module Re	ference	23
	4.6.1		Description	
	4.6.2	Member	Function/Subroutine Documentation	23
		4.6.2.1	killq	23
		4.6.2.2	loadq	23
	4.6.3	Member	Data Documentation	24
		4.6.3.1	qcol	24
		4.6.3.2	qdiag	24
		4.6.3.3	qn	24
		4.6.3.4	qne	24
		4.6.3.5	grow	24
		4.6.3.6	qscale	24
		4.6.3.7	qval	25
4.7	randon	n Module I	Reference	25
	4.7.1		Description	25
	4.7.2		Function/Subroutine Documentation	26
		4.7.2.1	bin_prob	26
		4.7.2.2	Ingamma	26

vi CONTENTS

5	File	Docum	entation		35
			4.9.2.2	state_dim	33
			4.9.2.1	obs_dim	33
		4.9.2	Member	Data Documentation	33
		4.9.1	Detailed	Description	33
	4.9	sizes N	Module Ref	erence	33
			4.8.3.6	rval	33
			4.8.3.5	rrow	33
			4.8.3.4	rne	33
			4.8.3.3	rn	32
			4.8.3.2	rdiag	32
			4.8.3.1	rcol	32
		4.8.3		Data Documentation	32
			4.8.2.2	loadr	32
			4.8.2.1	killr	32
		4.8.2		Function/Subroutine Documentation	32
	-	4.8.1		Description	31
	4.8	rdata N			31
			4.7.3.1	dp	31
		4.7.3		Data Documentation	31
			4.7.2.20	seed_random_number	31
			4.7.2.19	random_vori_mises	31
			4.7.2.19	random_t	30
			4.7.2.17	random_poisson	30
			4.7.2.16 4.7.2.17	random_order	30 30
			4.7.2.15	random_normal	29
			4.7.2.14	random_neg_binomial	29
			4.7.2.13	random_mvnorm	29
			4.7.2.12	random_inv_gauss	29
			4.7.2.11	random_gamma2	29
			4.7.2.10	random_gamma1	28
			4.7.2.9	random_gamma	28
			4.7.2.8	random_exponential	27
			4.7.2.7	random_chisq	27
			4.7.2.6	random_cauchy	27
			4.7.2.5	random_binomial2	27
			4.7.2.4	random_binomial1	26
			4.7.2.3	random_beta	26

CONTENTS vii

5.1	model_	_specific.f9	90 File Reference	35
	5.1.1	Function	Subroutine Documentation	35
		5.1.1.1	configure_model	35
		5.1.1.2	dist_st_ob	36
		5.1.1.3	$h \ldots \ldots \ldots \ldots \ldots \ldots \ldots$	37
		5.1.1.4	$ht \ldots \ldots$	38
		5.1.1.5	q	39
		5.1.1.6	qhalf	40
		5.1.1.7	$r \ldots \ldots \ldots \ldots$	41
		5.1.1.8	rhalf	41
		5.1.1.9	solve_hqht_plus_r	42
		5.1.1.10	solve_r	42
		5.1.1.11	solve_rhalf	43
5.2	src/con	itrolers/pf_	control.f90 File Reference	44
5.3	src/con	itrolers/pf_	couple.f90 File Reference	44
	5.3.1	Function	Subroutine Documentation	44
		5.3.1.1	empire	44
5.4	src/con	itrolers/pf_	parameters.dat File Reference	45
5.5	src/con	trolers/siz	es.f90 File Reference	45
5.6	src/data	a/Qdata.f9	00 File Reference	46
5.7	src/data	a/Rdata.f9	0 File Reference	46
5.8	src/DO	C_READN	ME.txt File Reference	46
5.9	src/filte	rs/determi	inistic_model.f90 File Reference	46
	5.9.1	Function	Subroutine Documentation	46
		5.9.1.1	deterministic_model	46
5.10	src/filte	rs/eakf_ar	nalysis.f90 File Reference	46
	5.10.1	Function	Subroutine Documentation	47
		5.10.1.1	eakf_analysis	47
5.11	src/filte	rs/enkf_sp	pecific.f90 File Reference	47
	5.11.1	Function	Subroutine Documentation	47
		5.11.1.1	get_local_observation_data	47
		5.11.1.2	h_local	48
		5.11.1.3	localise_enkf	48
		5.11.1.4	solve_rhalf_local	49
5.12	src/filte	rs/equivale	ent_weights_step.f90 File Reference	49
	5.12.1	Function	Subroutine Documentation	49
		5.12.1.1	equal_weight_filter	49
5.13	src/filte	rs/etkf_an	alysis.f90 File Reference	50
	5.13.1	Function	Subroutine Documentation	50
		5.13.1.1	etkf_analysis	51

viii CONTENTS

5.14	src/filte	rs/letkf_analys	is.f90 File Referenc	е		 	 	 	51
	5.14.1	Function/Sub	routine Documentat	ion		 	 	 	51
		5.14.1.1 letk	f_analysis			 	 	 	51
5.15	src/filte	rs/proposal_filt	er.f90 File Referend	ce		 	 	 	. 52
	5.15.1	Function/Sub	routine Documentat	ion		 	 	 	52
		5.15.1.1 pro	posal_filter			 	 	 	52
5.16	src/filte	rs/sir_filter.f90	File Reference			 	 	 	53
	5.16.1	Function/Sub	routine Documentat	ion		 	 	 	53
		5.16.1.1 sir_	filter			 	 	 	53
5.17	src/filte	rs/stochastic_r	nodel.f90 File Refer	rence		 	 	 	54
	5.17.1	Function/Sub	routine Documentat	ion		 	 	 	54
		5.17.1.1 che	ck_scaling			 	 	 	54
		5.17.1.2 sto	chastic_model			 	 	 	55
5.18	src/ope	rations/gen_ra	nd.f90 File Referen	ce		 	 	 	55
	5.18.1	Function/Sub	routine Documentat	ion		 	 	 	55
		5.18.1.1 mix	turerandomnumber	rs1d		 	 	 	56
		5.18.1.2 mix	turerandomnumber	rs2d		 	 	 	57
		5.18.1.3 nor	malrandomnumber	s1d		 	 	 	58
		5.18.1.4 nor	malrandomnumber	s2d		 	 	 	59
		5.18.1.5 ran	dom_seed_mpi			 	 	 	60
		5.18.1.6 uni	ormrandomnumber	rs1d		 	 	 	60
5.19	src/ope	rations/operato	or_wrappers.f90 File	e Referenc	e	 	 	 	61
	5.19.1	Function/Sub	routine Documentat	ion		 	 	 	61
		5.19.1.1 bpr	ime			 	 	 	61
		5.19.1.2 inn	erhqht_plus_r_1 .			 	 	 	62
		5.19.1.3 inn	err_1			 	 	 	63
		5.19.1.4 k				 	 	 	63
5.20	src/ope	rations/perturb	_particle.f90 File R	eference		 	 	 	64
	5.20.1	Function/Sub	routine Documentat	ion		 	 	 	64
		5.20.1.1 per	turb_particle			 	 	 	64
		5.20.1.2 upo	late_state			 	 	 	65
5.21	src/ope	rations/resamp	ole.f90 File Referen	ce		 	 	 	66
	5.21.1	Function/Sub	routine Documentat	ion		 	 	 	66
		5.21.1.1 res	ample			 	 	 	66
5.22	src/test	s/alltests.f90 F	ile Reference			 	 	 	67
	5.22.1	Function/Sub	routine Documentat	ion		 	 	 	67
		5.22.1.1 allte	ests			 	 	 	67
5.23	src/test	s/test_h.f90 Fi	le Reference			 	 	 	67
	5.23.1	Function/Sub	routine Documentat	ion		 	 	 	68
		5.23.1.1 test	<u>_</u> h			 	 	 	68

CONTENTS

5.24	src/tests/test_hqhtr.f90 File Reference	68
	5.24.1 Function/Subroutine Documentation	68
	5.24.1.1 test_hqhtr	68
5.25	5 src/tests/test_q.f90 File Reference	69
	5.25.1 Function/Subroutine Documentation	69
	5.25.1.1 test_q	69
5.26	S src/tests/test_r.f90 File Reference	70
	5.26.1 Function/Subroutine Documentation	70
	5.26.1.1 test_r	70
5.27	7 src/tests/tests.f90 File Reference	71
	5.27.1 Function/Subroutine Documentation	71
	5.27.1.1 h_tests	71
	5.27.1.2 hqhtr_tests	72
	5.27.1.3 q_tests	73
	5.27.1.4 r_tests	74
5.28	3 src/utils/comms.f90 File Reference	75
5.29	9 src/utils/data_io.f90 File Reference	75
	5.29.1 Function/Subroutine Documentation	76
	5.29.1.1 get_observation_data	76
	5.29.1.2 get_state	76
	5.29.1.3 output_from_pf	77
	5.29.1.4 save_observation_data	77
	5.29.1.5 save_state	77
	5.29.1.6 save_truth	78
5.30	o src/utils/diagnostics.f90 File Reference	78
	5.30.1 Function/Subroutine Documentation	78
	5.30.1.1 diagnostics	78
	5.30.1.2 trajectories	79
5.31	src/utils/genQ.f90 File Reference	79
	5.31.1 Function/Subroutine Documentation	79
	5.31.1.1 genq	79
5.32	2 src/utils/histogram.f90 File Reference	80
5.33	3 src/utils/quicksort.f90 File Reference	80
	5.33.1 Function/Subroutine Documentation	80
	5.33.1.1 insertionsort_d	80
	5.33.1.2 quicksort_d	81
5.34	src/utils/random_d.f90 File Reference	82
Index		83

# **Chapter 1**

# **EMPIRE Data Assimilation Documentation**

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Date

Time-stamp: <2014-10-08 16:40:26 pbrowne>

# 1.1 Downloading

These codes are hosted on www.bitbucket.org and can be obtained with the following commands:

1 git clone https://www.bitbucket.org/pbrowne/empire-data-assimilation.git

To upgrade to the latest versions of the codes, use the following command:

1 git pull https://www.bitbucket.org/pbrowne/empire-data-assimilation.git

#### Copyright

These codes are distributed under the GNU GPU v3 License. See LICENSE.txt.

# 1.2 Compiling

# 1.2.1 Compilation of the source code

The Makefile must be editted for the specific compiler setup. In the main directory you will find the file Makefile. Edit the variables as follows:

• FC The fortran compiler

This has been tested with gfortran 4.8.2, crayftn 8.2.6 and ifort 14.0.1.106

- FCOPTS The options for the fortran compiler
- $\bullet$  LIB\_LIST The libraries to be called. Note this must include BLAS and LAPACK
- MODFLAG The flag to specify where module files should be placed by the fortran complier. Examples are

```
- gfortran: -J
- ifort: -module
- crayftn: -em -J
- pgfortran: -module
```

To compile the source code, simply then type the command

```
1 make
```

If successful, the following executables are created in the bin/ folder:

- · empire
- · alltests
- test h
- · test hghtr
- test\_q
- test r

To remove the object and executable files if compilation fails for some reason, run the following:

```
1 make clean
```

# 1.2.2 Compilation of the documentation

Documentation of the code is automatically generated using Doxygen, dot and pdflatex.

All of these packages must be installed for the following to work.

```
1 make docs
```

This will make an html webpage for the code, the mainpage for which is located in doc/html/index.html.

A latex version of the documentation will be built to the file doc/latex/refman.pdf.

To simply make the html version of the documentation (if pdflatex is not available) then use the command

```
1 make doc_html
```

# 1.3 Customising for specific models

This is where the science and all the effort should happen!!

The file model\_specific.f90 should be editted for the specific model which you wish to use. This contains a number of subroutines which need to be adapted for the model and the observation network. We list these subsequently.

- configure\_model This is called early in the code and can be used to read in any data from files before subsequently using them in the below operations.
- h This is the observation operator
- · ht This is the transpose of the observation operator
- r This is the observation error covariance matrix R

1.4 Testing 3

- rhalf This is the square root of the observation error covariance matrix  $R^{\frac{1}{2}}$
- solve\_r This is a linear solve with the observation error covariance matrix, i.e. given b, find x such that Rx = b or indeed,  $x = R^{-1}b$
- solve\_rhalf This is a linear solve with the square root of the observation error covariance matrix, i.e. given b, find x such that  $R^{\frac{1}{2}}x = b$  or indeed,  $x = R^{-\frac{1}{2}}b$
- q This is the model error covariance matrix Q
- qhalf This is the square root model error covariance matrix  $Q^{\frac{1}{2}}$
- solve\_hqht\_plus\_r This is a linear solve with the matrix  $(HQH^T + R)$
- dist\_st\_ob This specifies the distance between a an element of the state vector and an element of the observation vector

Not all of these subroutines will be required for each filtering method you wish to use, so it may be advantageous to only implement the necessary ones.

# 1.4 Testing

You can test your user supplied routines by running the test codes found in the folder bin/.

These are by no means full-proof ways of ensuring that you have implemented things correctly, but should at least check what you have done for logical consistency.

For example, they will test if  $HH^Tx = x$ , and if  $Q^{\frac{1}{2}}Q^{\frac{1}{2}}x = Qx$  for various different vectors x.

# 1.5 Linking to your model using EMPIRE

Full instructions on how to put the EMPIRE MPI commands into a new model can be found at www.met. $\leftarrow$  reading.ac.uk/ $\sim$ darc/empire.

# 1.6 Running

For example, to run **N\_MDL** copies of the model with **N\_DA** copies of empire, then the following are possible:

```
1 mpirun -np N_MDL model_executable : -np N_DA empire
1 aprun -n N_MDL -N N_MDL model_executable : -n N_DA -N N_DA empire
```

The empire executable is controlled by the namelist data file pf\_parameters.dat. As such, this file should be put in the directory where empire is executed.

# 1.7 Examples

In the directory examples there is currently one example of how to use EMPIRE, specifically with the Lorenz 1996 model. In the directory you will find an example model\_specific.f90 file setup for that model, along with a file instructions.txt which will lead you step by step through how to run a twin experiment.

# 1.8 Bug Reports and Functionality Requests

While the code is not too large, you may email me the issue or request here.

However there is a webpage set up for this:

https://bitbucket.org/pbrowne/empire-data-assimilation/issues

# Chapter 2

# **Data Type Index**

# 2.1 Data Types List

Here are the data types with brief descriptions:

COMMIS	
Module containing EMPIRE coupling data	9
histogram_data	
Module to control what variables are used to generate rank histograms	11
hqht_plus_r	13
pf_control	
Module pf_control holds all the information to control the the main program	14
pf_control::pf_control_type	17
<del>qdata</del>	
Module as a place to store user specified data for $Q$	23
random	
A module for random number generation from the following distributions:	25
rdata	
Module to hold user supplied data for $R$ observation error covariance matrix $\ldots \ldots \ldots$	31
sizes	
Module that stores the dimension of observation and state spaces	33

6 **Data Type Index** 

# **Chapter 3**

# File Index

# 3.1 File List

Here is a list of all files with brief descriptions:

model_specific.f90
src/controlers/pf_control.f90
src/controlers/pf_couple.f90
src/controlers/pf_parameters.dat
src/controlers/sizes.f90
src/data/Qdata.f90
src/data/Rdata.f90
src/filters/deterministic_model.f90
src/filters/eakf_analysis.f90
src/filters/enkf_specific.f90
src/filters/equivalent_weights_step.f90
src/filters/etkf_analysis.f90
src/filters/letkf_analysis.f90
src/filters/proposal_filter.f90
src/filters/sir_filter.f90
src/filters/stochastic_model.f90
src/operations/gen_rand.f90
src/operations/operator_wrappers.f90
src/operations/perturb_particle.f90
src/operations/resample.f90
src/tests/alltests.f90
src/tests/test_h.f90
src/tests/test_hqhtr.f90
src/tests/test_q.f90
src/tests/test_r.f90
src/tests/tests.f90
src/utils/comms.f90
src/utils/data_io.f90
src/utils/diagnostics.f90
src/utils/genQ.f90
src/utils/histogram.f90
src/utils/quicksort.f90
src/utils/random_d f90

8 File Index

# Chapter 4

# **Data Type Documentation**

# 4.1 comms Module Reference

Module containing EMPIRE coupling data.

#### **Public Member Functions**

- · subroutine allocate data
- subroutine deallocate\_data
- subroutine initialise\_mpi

subroutine to make EMPIRE connections and saves details into pf\_control module

# **Public Attributes**

• integer cpl\_mpi\_comm

the communicator between the empire codes and the model master nodes

• integer mype\_id

the rank of this process on MPI\_COMM\_WORLD

· integer myrank

the rank of this process on CPL\_MPI\_COMM

integer nproc

the total number of processes

integer pf\_mpi\_comm

the communicator between DA processes

integer pfrank

the rank of this process on PF\_MPI\_COMM

integer npfs

the total number of DA processes

• integer, dimension(:), allocatable gblcount

the number of ensemble members associated with each DA process

• integer, dimension(:), allocatable gbldisp

the displacements of each each ensemble member relative to pfrank=0. VERY useful for mpi\_gatherv and mpi\_ $\leftarrow$  scatterv on pf\_mpi\_comm

# 4.1.1 Detailed Description

Module containing EMPIRE coupling data.

Definition at line 30 of file comms.f90.

# 4.1.2 Member Function/Subroutine Documentation

4.1.2.1 subroutine comms::allocate\_data( )

Definition at line 47 of file comms.f90.

4.1.2.2 subroutine comms::deallocate\_data ( )

Definition at line 53 of file comms.f90.

Here is the caller graph for this function:



# 4.1.2.3 subroutine comms::initialise\_mpi ( )

subroutine to make EMPIRE connections and saves details into pf\_control module Definition at line 60 of file comms.f90.

Here is the caller graph for this function:



# 4.1.3 Member Data Documentation

# 4.1.3.1 integer comms::cpl\_mpi\_comm

the communicator between the empire codes and the model master nodes Definition at line 31 of file comms.f90.

# 4.1.3.2 integer, dimension(:), allocatable comms::gblcount

the number of ensemble members associated with each DA process Definition at line 39 of file comms.f90.

#### 4.1.3.3 integer, dimension(:), allocatable comms::gbldisp

the displacements of each each ensemble member relative to pfrank=0. VERY useful for mpi\_gatherv and mpi\_coatterv on pf\_mpi\_comm

Definition at line 41 of file comms.f90.

#### 4.1.3.4 integer comms::mype\_id

the rank of this process on MPI\_COMM\_WORLD

Definition at line 33 of file comms.f90.

#### 4.1.3.5 integer comms::myrank

the rank of this process on CPL\_MPI\_COMM

Definition at line 34 of file comms.f90.

#### 4.1.3.6 integer comms::npfs

the total number of DA processes

Definition at line 38 of file comms.f90.

#### 4.1.3.7 integer comms::nproc

the total number of processes

Definition at line 35 of file comms.f90.

# 4.1.3.8 integer comms::pf\_mpi\_comm

the communicator between DA processes

Definition at line 36 of file comms.f90.

# 4.1.3.9 integer comms::pfrank

the rank of this process on PF\_MPI\_COMM

Definition at line 37 of file comms.f90.

The documentation for this module was generated from the following file:

• src/utils/comms.f90

# 4.2 histogram\_data Module Reference

Module to control what variables are used to generate rank histograms.

# **Public Member Functions**

subroutine load\_histogram\_data
 subroutine to read from variables\_hist.dat which variables to be used to make the rank histograms

subroutine kill\_histogram\_data
 subroutine to clean up arrays used in rank histograms

#### **Public Attributes**

- integer, dimension(:), allocatable rank\_hist\_list
- integer, dimension(:), allocatable rank\_hist\_nums
- integer rhl n
- integer rhn n

#### 4.2.1 Detailed Description

Module to control what variables are used to generate rank histograms.

Definition at line 29 of file histogram.f90.

#### 4.2.2 Member Function/Subroutine Documentation

4.2.2.1 subroutine histogram\_data::kill\_histogram\_data( )

subroutine to clean up arrays used in rank histograms

Definition at line 57 of file histogram.f90.

4.2.2.2 subroutine histogram\_data::load\_histogram\_data ( )

subroutine to read from variables\_hist.dat which variables to be used to make the rank histograms Definition at line 37 of file histogram.f90.

#### 4.2.3 Member Data Documentation

4.2.3.1 integer, dimension(:), allocatable histogram\_data::rank\_hist\_list

Definition at line 30 of file histogram.f90.

4.2.3.2 integer, dimension(:), allocatable histogram\_data::rank\_hist\_nums

Definition at line 31 of file histogram.f90.

4.2.3.3 integer histogram\_data::rhl\_n

Definition at line 32 of file histogram.f90.

4.2.3.4 integer histogram\_data::rhn\_n

Definition at line 32 of file histogram.f90.

The documentation for this module was generated from the following file:

• src/utils/histogram.f90

# 4.3 hqht\_plus\_r Module Reference

# **Public Member Functions**

- subroutine load\_hqhtr
- subroutine hqhtr\_factor
- subroutine kill\_hqhtr

# 4.3.1 Detailed Description

Definition at line 59 of file Rdata.f90.

# 4.3.2 Member Function/Subroutine Documentation

4.3.2.1 subroutine hqht\_plus\_r::hqhtr\_factor ( )

Definition at line 69 of file Rdata.f90.

Here is the caller graph for this function:



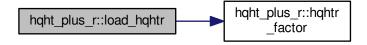
4.3.2.2 subroutine hqht\_plus\_r::kill\_hqhtr ( )

Definition at line 74 of file Rdata.f90.

4.3.2.3 subroutine hqht\_plus\_r::load\_hqhtr ( )

Definition at line 65 of file Rdata.f90.

Here is the call graph for this function:

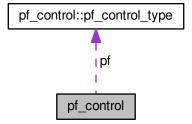


The documentation for this module was generated from the following file:

• src/data/Rdata.f90

# 4.4 pf\_control Module Reference

module pf\_control holds all the information to control the the main program Collaboration diagram for pf\_control:



# **Data Types**

type pf\_control\_type

# **Public Member Functions**

- subroutine set\_pf\_controls

  subroutine to ensure pf\_control data is ok
- subroutine parse\_pf\_parameters
   subroutine to read the namelist file and save it to pf datatype Here we read pf\_parameters.dat
- subroutine allocate\_pf
   subroutine to allocate space for the filtering code
- subroutine deallocate\_pf
  subroutine to deallocate space for the filtering code

# Public Attributes

type(pf\_control\_type), save pf
 the derived data type holding all controlling data

# 4.4.1 Detailed Description

module pf\_control holds all the information to control the the main program Definition at line 29 of file pf\_control.f90.

# 4.4.2 Member Function/Subroutine Documentation

# 4.4.2.1 subroutine pf\_control::allocate\_pf ( )

subroutine to allocate space for the filtering code

Definition at line 343 of file pf\_control.f90.

Here is the caller graph for this function:



# 4.4.2.2 subroutine pf\_control::deallocate\_pf ( )

subroutine to deallocate space for the filtering code

Definition at line 365 of file pf\_control.f90.

#### 4.4.2.3 subroutine pf\_control::parse\_pf\_parameters ( )

subroutine to read the namelist file and save it to pf datatype Here we read pf\_parameters.dat pf\_parameters.dat is a fortran namelist file. As such, within it there must be a line beginning &pf\_params

To make it (probably) work, ensure there is a forward slash on the penultimate line and a blank line to end the file This is just the fortran standard for namelists though.

On to the content...in any order, the pf\_parameters.dat may contain the following things: Integers:

- time\_obs
- · time bwn obs

Reals, double precision:

- nudgefac
- nfac
- ufac
- Qscale
- keep
- rho
- len

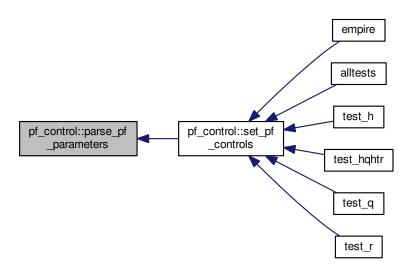
- 2 Characters:
  - type
- 1 Character:
  - · init

# Logicals:

- gen\_Q
- gen\_data
- use\_talagrand
- use\_weak
- use\_var
- use\_traj
- use\_rmse
- human\_readable

Definition at line 163 of file pf\_control.f90.

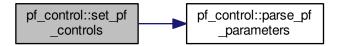
Here is the caller graph for this function:



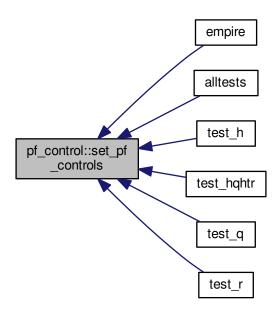
4.4.2.4 subroutine pf\_control::set\_pf\_controls ( )

subroutine to ensure pf\_control data is ok

Here is the call graph for this function:



Here is the caller graph for this function:



# 4.4.3 Member Data Documentation

# 4.4.3.1 type(pf\_control\_type), save pf\_control::pf

the derived data type holding all controlling data

Definition at line 91 of file pf\_control.f90.

The documentation for this module was generated from the following file:

• src/controlers/pf\_control.f90

# 4.5 pf\_control::pf\_control\_type Type Reference

#### **Public Attributes**

· integer nens

the total number of ensemble members

real(kind=kind(1.0d0)), dimension(:), allocatable weight

the negative log of the weights of the particles

• integer time\_obs

the number of observations we will assimilate

integer time\_bwn\_obs

the number of model timesteps between observations

• real(kind=kind(1.0d0)) nudgefac

the nudging factor

· logical gen\_data

true generates synthetic obs for a twin experiment

· logical gen\_q

true attempts to build up Q from long model run

logical human\_readable

unused

• integer timestep =0

the current timestep as the model progresses

real(kind=kind(1.0d0)), dimension(:,:), allocatable psi

state vector of ensemble members on this mpi process

real(kind=kind(1.0d0)), dimension(:), allocatable mean

mean state vector

real(kind=kind(1.0d0)) nfac

standard deviation of normal distribution in mixture density

real(kind=kind(1.0d0)) ufac

half width of the uniform distribution in mixture density

- real(kind=kind(1.0d0)) efac
- real(kind=kind(1.0d0)) keep

proportion of particles to keep in EWPF EW step

real(kind=kind(1.0d0)) time

dunno

real(kind=kind(1.0d0)) qscale

scalar to multiply Q by

real(kind=kind(1.0d0)) rho

enkf inflation factor so that  $P_f = (1 + \rho)P_f$ 

• real(kind=kind(1.0d0)) len

R localisation length scale.

integer couple\_root

empire master processor

· logical use\_talagrand

switch if true outputs rank histograms

logical use\_weak

switch unused

logical use\_mean

switch if true outputs ensemble mean

· logical use\_var

switch if true outputs ensemble variance

logical use\_traj

switch if true outputs trajectories

logical use\_rmse

switch if true outputs Root Mean Square Errors

 integer, dimension(:,:), allocatable talagrand storage for rank histograms

integer count

number of ensemble members associated with this MPI process

• integer, dimension(:), allocatable particles

particles associates with this MPI process

· character(2) type

which filter to use currently this has a number of options:

• character(1) init

which method to initialise ensemble currently this has a number of options:

# 4.5.1 Detailed Description

Definition at line 31 of file pf\_control.f90.

#### 4.5.2 Member Data Documentation

4.5.2.1 integer pf\_control::pf\_control\_type::count

number of ensemble members associated with this MPI process

Definition at line 64 of file pf\_control.f90.

4.5.2.2 integer pf\_control::pf\_control\_type::couple\_root

empire master processor

Definition at line 56 of file pf\_control.f90.

4.5.2.3 real(kind=kind(1.0d0)) pf\_control::pf\_control\_type::efac

Definition at line 46 of file pf\_control.f90.

4.5.2.4 logical pf\_control::pf\_control\_type::gen\_data

true generates synthetic obs for a twin experiment

Definition at line 37 of file pf\_control.f90.

4.5.2.5 logical pf\_control::pf\_control\_type::gen\_q

true attempts to build up Q from long model run

Definition at line 38 of file pf\_control.f90.

4.5.2.6 logical pf\_control::pf\_control\_type::human\_readable

unused

Definition at line 40 of file pf\_control.f90.

4.5.2.7 character(1) pf\_control::pf\_control\_type::init

which method to initialise ensemble currently this has a number of options:

- N perturb around the model initial conditions with random noise distributed  $\mathcal{N}(0,I)$
- P perturb around the model initial conditions with random noise distributed  $\mathcal{N}(0,Q)$
- R read model states from rstrt folder where each ensemble member is stored in the file rstrt/##.state
- S read model states from start folder where each ensemble member is stored in the file start/##.state

Definition at line 74 of file pf control.f90.

4.5.2.8 real(kind=kind(1.0d0)) pf\_control::pf\_control\_type::keep

proportion of particles to keep in EWPF EW step

Definition at line 47 of file pf control.f90.

4.5.2.9 real(kind=kind(1.0d0)) pf\_control::pf\_control\_type::len

R localisation length scale.

Definition at line 54 of file pf\_control.f90.

4.5.2.10 real(kind=kind(1.0d0)), dimension(:), allocatable pf\_control::pf\_control\_type::mean

mean state vector

Definition at line 43 of file pf\_control.f90.

4.5.2.11 integer pf\_control::pf\_control\_type::nens

the total number of ensemble members

Definition at line 32 of file pf\_control.f90.

4.5.2.12 real(kind=kind(1.0d0)) pf\_control::pf\_control\_type::nfac

standard deviation of normal distribution in mixture density

Definition at line 44 of file pf\_control.f90.

4.5.2.13 real(kind=kind(1.0d0)) pf\_control::pf\_control\_type::nudgefac

the nudging factor

Definition at line 36 of file pf\_control.f90.

4.5.2.14 integer, dimension(:), allocatable pf\_control::pf\_control\_type::particles

particles associates with this MPI process

Definition at line 65 of file pf\_control.f90.

4.5.2.15 real(kind=kind(1.0d0)), dimension(:,:), allocatable pf\_control::pf\_control\_type::psi

state vector of ensemble members on this mpi process

Definition at line 42 of file pf\_control.f90.

4.5.2.16 real(kind=kind(1.0d0)) pf\_control::pf\_control\_type::qscale

scalar to multiply Q by

Definition at line 49 of file pf\_control.f90.

4.5.2.17 real(kind=kind(1.0d0)) pf\_control::pf\_control\_type::rho

enkf inflation factor so that  $P_f = (1 + \rho)P_f$ 

Definition at line 51 of file pf control.f90.

4.5.2.18 integer, dimension(:,:), allocatable pf\_control::pf\_control\_type::talagrand

storage for rank histograms

Definition at line 63 of file pf\_control.f90.

4.5.2.19 real(kind=kind(1.0d0)) pf\_control::pf\_control\_type::time

dunno

Definition at line 48 of file pf\_control.f90.

4.5.2.20 integer pf\_control::pf\_control\_type::time\_bwn\_obs

the number of model timesteps between observations

Definition at line 35 of file pf\_control.f90.

4.5.2.21 integer pf\_control::pf\_control\_type::time\_obs

the number of observations we will assimilate

Definition at line 34 of file pf\_control.f90.

4.5.2.22 integer pf\_control::pf\_control\_type::timestep =0

the current timestep as the model progresses

Definition at line 41 of file pf control.f90.

4.5.2.23 character(2) pf\_control::pf\_control\_type::type

which filter to use currently this has a number of options:

- SE a stochastic ensemble
- SI the SIR filter
- ET the L-ETKF

• EW - the Equivalent Weights particle filter

Definition at line 66 of file pf\_control.f90.

4.5.2.24 real(kind=kind(1.0d0)) pf\_control::pf\_control\_type::ufac

half width of the uniform distribution in mixture density

Definition at line 45 of file pf\_control.f90.

4.5.2.25 logical pf\_control::pf\_control\_type::use\_mean

switch if true outputs ensemble mean

Definition at line 59 of file pf control.f90.

4.5.2.26 logical pf\_control::pf\_control\_type::use\_rmse

switch if true outputs Root Mean Square Errors

Definition at line 62 of file pf\_control.f90.

4.5.2.27 logical pf\_control::pf\_control\_type::use\_talagrand

switch if true outputs rank histograms

Definition at line 57 of file pf\_control.f90.

4.5.2.28 logical pf\_control::pf\_control\_type::use\_traj

switch if true outputs trajectories

Definition at line 61 of file pf\_control.f90.

4.5.2.29 logical pf\_control::pf\_control\_type::use\_var

switch if true outputs ensemble variance

Definition at line 60 of file pf\_control.f90.

4.5.2.30 logical pf\_control::pf\_control\_type::use\_weak

switch unused

Definition at line 58 of file pf\_control.f90.

4.5.2.31 real(kind=kind(1.0d0)), dimension(:), allocatable pf\_control::pf\_control\_type::weight

the negative log of the weights of the particles

Definition at line 33 of file pf\_control.f90.

The documentation for this type was generated from the following file:

• src/controlers/pf\_control.f90

# 4.6 qdata Module Reference

Module as a place to store user specified data for Q.

#### **Public Member Functions**

subroutine loadq

Subroutine to load in user data for Q.

subroutine killq

#### **Public Attributes**

- integer qn
- integer qne
- integer, dimension(:), allocatable grow
- integer, dimension(:), allocatable qcol
- real(kind=kind(1.0d0)), dimension(:), allocatable qval
- real(kind=kind(1.0d0)), dimension(:), allocatable qdiag
- real(kind=kind(1.0d0)) qscale

# 4.6.1 Detailed Description

Module as a place to store user specified data for Q.

· the model error covariance matrix

Definition at line 30 of file Qdata.f90.

# 4.6.2 Member Function/Subroutine Documentation

4.6.2.1 subroutine qdata::killq ( )

SUbroutine to deallocate user data for Q

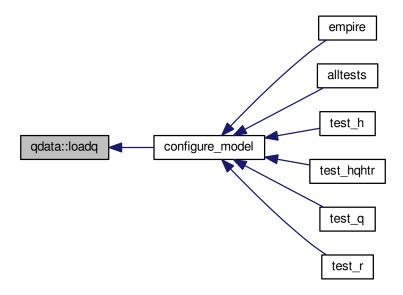
Definition at line 44 of file Qdata.f90.

4.6.2.2 subroutine qdata::loadq ( )

Subroutine to load in user data for Q.

Definition at line 38 of file Qdata.f90.

Here is the caller graph for this function:



# 4.6.3 Member Data Documentation

4.6.3.1 integer, dimension(:), allocatable qdata::qcol

Definition at line 33 of file Qdata.f90.

4.6.3.2 real(kind=kind(1.0d0)), dimension(:), allocatable qdata::qdiag

Definition at line 34 of file Qdata.f90.

4.6.3.3 integer qdata::qn

Definition at line 32 of file Qdata.f90.

4.6.3.4 integer qdata::qne

Definition at line 32 of file Qdata.f90.

4.6.3.5 integer, dimension(:), allocatable qdata::qrow

Definition at line 33 of file Qdata.f90.

4.6.3.6 real(kind=kind(1.0d0)) qdata::qscale

Definition at line 35 of file Qdata.f90.

4.6.3.7 real(kind=kind(1.0d0)), dimension(:), allocatable qdata::qval

Definition at line 34 of file Qdata.f90.

The documentation for this module was generated from the following file:

src/data/Qdata.f90

#### 4.7 random Module Reference

A module for random number generation from the following distributions:

#### **Public Member Functions**

- real(kind=kind(1.0d+0)) function random\_normal ()
   function to get random normal with zero mean and stdev 1
- real(kind=kind(1.0d+0)) function random\_gamma (s, first)
- real(kind=kind(1.0d+0)) function random\_gamma1 (s, first)
- real(kind=kind(1.0d+0)) function random gamma2 (s, first)
- real(kind=kind(1.0d+0)) function random\_chisq (ndf, first)
- real(kind=kind(1.0d+0)) function random exponential ()
- real(kind=kind(1.0d+0)) function random weibull (a)
- real(kind=kind(1.0d+0)) function random beta (aa, bb, first)
- real(kind=kind(1.0d+0)) function random\_t (m)
- subroutine random\_mvnorm (n, h, d, f, first, x, ier)
- real(kind=kind(1.0d+0)) function random\_inv\_gauss (h, b, first)
- integer function random poisson (mu, first)
- integer function random binomial1 (n, p, first)
- real(kind=kind(1.0d+0)) function bin\_prob (n, p, r)
- real(dp) function Ingamma (x)
- integer function random\_binomial2 (n, pp, first)
- integer function random\_neg\_binomial (sk, p)
- real(kind=kind(1.0d+0)) function random\_von\_mises (k, first)
- real(kind=kind(1.0d+0)) function random\_cauchy ()
- subroutine random\_order (order, n)
- subroutine seed\_random\_number (iounit)

# **Public Attributes**

• integer, parameter dp = SELECTED\_REAL\_KIND(12, 60)

# 4.7.1 Detailed Description

A module for random number generation from the following distributions:

Distribution Function/subroutine name

Normal (Gaussian) random\_normal Gamma random\_gamma Chi-squared random\_chisq Exponential random\_chisq exponential Weibull random\_Weibull Beta random\_beta t random\_t Multivariate normal random\_mvnorm Generalized inverse Gaussian random\_inv\_gauss Poisson random\_Poisson Binomial random\_binomial1 \* random\_chinomial2 \* Negative binomial random\_neg\_binomial von Mises random\_von\_Mises Cauchy random\_Cauchy

Definition at line 22 of file random\_d.f90.

# 4.7.2 Member Function/Subroutine Documentation

4.7.2.1 real(kind=kind(1.0d+0)) function random::bin\_prob ( integer, intent(in) *n*, real(kind=kind(1.0d+0)), intent(in) *p*, integer, intent(in) *r* )

Definition at line 1000 of file random\_d.f90.

Here is the call graph for this function:



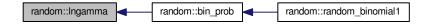
Here is the caller graph for this function:



4.7.2.2 real (dp) function random::Ingamma (real (dp), intent(in) x)

Definition at line 1018 of file random\_d.f90.

Here is the caller graph for this function:



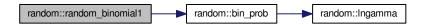
4.7.2.3 real(kind=kind(1.0d+0)) function random::random\_beta ( real(kind=kind(1.0d+0)), intent(in) aa, real(kind=kind(1.0d+0)), intent(in) bb, logical, intent(in) first )

Definition at line 371 of file random\_d.f90.

4.7.2.4 integer function random::random\_binomial1 ( integer, intent(in) *n*, real(kind=kind(1.0d+0)), intent(in) *p*, logical, intent(in) *first* )

Definition at line 923 of file random\_d.f90.

Here is the call graph for this function:



4.7.2.5 integer function random::random\_binomial2 ( integer, intent(in) *n*, real(kind=kind(1.0d+0)), intent(in) *pp*, logical, intent(in) *first* )

Definition at line 1082 of file random\_d.f90.

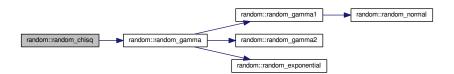
4.7.2.6 real(kind=kind(1.0d+0)) function random::random\_cauchy ( )

Definition at line 1517 of file random\_d.f90.

4.7.2.7 real(kind=kind(1.0d+0)) function random::random\_chisq ( integer, intent(in) ndf, logical, intent(in) first )

Definition at line 308 of file random\_d.f90.

Here is the call graph for this function:



4.7.2.8 real(kind=kind(1.0d+0)) function random::random\_exponential()

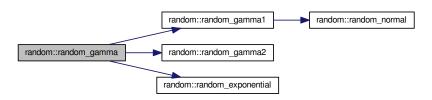
Definition at line 324 of file random\_d.f90.



4.7.2.9 real(kind=kind(1.0d+0)) function random::random\_gamma ( real(kind=kind(1.0d+0)), intent(in) s, logical, intent(in) first )

Definition at line 154 of file random\_d.f90.

Here is the call graph for this function:



Here is the caller graph for this function:



4.7.2.10 real(kind=kind(1.0d+0)) function random::random\_gamma1 ( real(kind=kind(1.0d+0)), intent(in) s, logical, intent(in) first

Definition at line 189 of file random\_d.f90.

Here is the call graph for this function:





4.7.2.11 real(kind=kind(1.0d+0)) function random::random\_gamma2 ( real(kind=kind(1.0d+0)), intent(in) s, logical, intent(in) first

Definition at line 238 of file random\_d.f90.

Here is the caller graph for this function:



4.7.2.12 real(kind=kind(1.0d+0)) function random::random\_inv\_gauss ( real(kind=kind(1.0d+0)), intent(in) h, real(kind=kind(1.0d+0)), intent(in) b, logical, intent(in) first )

Definition at line 610 of file random d.f90.

4.7.2.13 subroutine random::random\_mvnorm ( integer, intent(in) *n*, real(kind=kind(1.0d+0)), dimension(:), intent(in) *h*, real(kind=kind(1.0d+0)), dimension(:), intent(in) *d*, real(kind=kind(1.0d+0)), dimension(:), intent(inout) *f*, logical, intent(in) *first*, real(kind=kind(1.0d+0)), dimension(:), intent(out) *x*, integer, intent(out) *ier* )

Definition at line 509 of file random d.f90.

Here is the call graph for this function:



4.7.2.14 integer function random::random\_neg\_binomial ( real(kind=kind(1.0d+0)), intent(in) sk, real(kind=kind(1.0d+0)), intent(in) p )

Definition at line 1314 of file random d.f90.

4.7.2.15 real(kind=kind(1.0d+0)) function random::random\_normal ( )

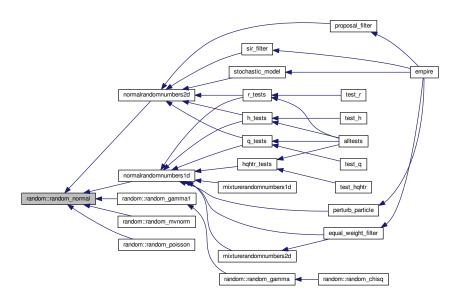
function to get random normal with zero mean and stdev 1

Returns

fn\_val

Definition at line 108 of file random\_d.f90.

Here is the caller graph for this function:



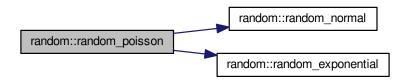
4.7.2.16 subroutine random::random\_order ( integer, dimension(n), intent(out) order, integer, intent(in) n )

Definition at line 1539 of file random\_d.f90.

4.7.2.17 integer function random::random\_poisson ( real(kind=kind(1.0d+0)), intent(in) mu, logical, intent(in) first )

Definition at line 681 of file random\_d.f90.

Here is the call graph for this function:



4.7.2.18 real(kind=kind(1.0d+0)) function random::random\_t ( integer, intent(in) m )

Definition at line 448 of file random\_d.f90.

4.7.2.19 real(kind=kind(1.0d+0)) function random::random\_von\_mises ( real(kind=kind(1.0d+0)), intent(in) k, logical, intent(in) first )

Definition at line 1389 of file random\_d.f90.

4.8 rdata Module Reference 31

4.7.2.20 real(kind=kind(1.0d+0)) function random::random\_weibull ( real(kind=kind(1.0d+0)), intent(in) a )

Definition at line 351 of file random\_d.f90.

Here is the call graph for this function:



4.7.2.21 subroutine random::seed\_random\_number ( integer, intent(in) iounit )

Definition at line 1573 of file random\_d.f90.

#### 4.7.3 Member Data Documentation

4.7.3.1 integer, parameter random::dp = SELECTED\_REAL\_KIND(12, 60)

Definition at line 101 of file random\_d.f90.

The documentation for this module was generated from the following file:

• src/utils/random\_d.f90

### 4.8 rdata Module Reference

Module to hold user supplied data for *R* observation error covariance matrix.

### **Public Member Functions**

- subroutine loadr
   Subroutine to load data for R.
- subroutine killr

#### **Public Attributes**

- integer rn
- integer rne
- integer, dimension(:), allocatable rrow
- integer, dimension(:), allocatable rcol
- real(kind=kind(1.0d0)), dimension(:), allocatable rval
- real(kind=kind(1.0d0)), dimension(:), allocatable rdiag

# 4.8.1 Detailed Description

Module to hold user supplied data for *R* observation error covariance matrix.

Definition at line 29 of file Rdata.f90.

### 4.8.2 Member Function/Subroutine Documentation

### 4.8.2.1 subroutine rdata::killr ( )

SUbroutine to deallocate R data

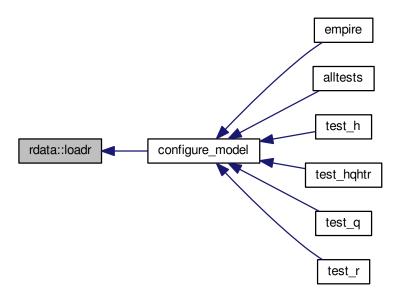
Definition at line 49 of file Rdata.f90.

### 4.8.2.2 subroutine rdata::loadr ( )

Subroutine to load data for R.

Definition at line 36 of file Rdata.f90.

Here is the caller graph for this function:



# 4.8.3 Member Data Documentation

### 4.8.3.1 integer, dimension(:), allocatable rdata::rcol

Definition at line 32 of file Rdata.f90.

# 4.8.3.2 real(kind=kind(1.0d0)), dimension(:), allocatable rdata::rdiag

Definition at line 33 of file Rdata.f90.

## 4.8.3.3 integer rdata::rn

Definition at line 31 of file Rdata.f90.

4.9 sizes Module Reference 33

#### 4.8.3.4 integer rdata::rne

Definition at line 31 of file Rdata.f90.

#### 4.8.3.5 integer, dimension(:), allocatable rdata::rrow

Definition at line 32 of file Rdata.f90.

#### 4.8.3.6 real(kind=kind(1.0d0)), dimension(:), allocatable rdata::rval

Definition at line 33 of file Rdata.f90.

The documentation for this module was generated from the following file:

• src/data/Rdata.f90

### 4.9 sizes Module Reference

Module that stores the dimension of observation and state spaces.

### **Public Attributes**

integer obs\_dim
 size of the observation space

· integer state dim

dimension of the model

### 4.9.1 Detailed Description

Module that stores the dimension of observation and state spaces.

Definition at line 29 of file sizes.f90.

### 4.9.2 Member Data Documentation

4.9.2.1 integer sizes::obs\_dim

size of the observation space

Definition at line 31 of file sizes.f90.

4.9.2.2 integer sizes::state\_dim

dimension of the model

Definition at line 32 of file sizes.f90.

The documentation for this module was generated from the following file:

• src/controlers/sizes.f90

# **Chapter 5**

# **File Documentation**

# 5.1 model\_specific.f90 File Reference

#### **Functions/Subroutines**

```
• subroutine configure_model
```

subroutine called initially to set up details and data for model specific functions

• subroutine solve\_r (obsDim, nrhs, y, v, t)

subroutine to take an observation vector y and return v in observation space.

• subroutine solve\_rhalf (obsdim, nrhs, y, v, t)

subroutine to take an observation vector y and return v in observation space.

subroutine solve\_hqht\_plus\_r (obsdim, y, v, t)

subroutine to take an observation vector y and return v in observation space.

• subroutine q (nrhs, x, Qx)

subroutine to take a full state vector x and return Qx in state space.

• subroutine qhalf (nrhs, x, Qx)

subroutine to take a full state vector x and return  $Q^{1/2}x$  in state space.

• subroutine r (obsDim, nrhs, y, Ry, t)

subroutine to take an observation vector x and return Rx in observation space.

• subroutine rhalf (obsDim, nrhs, y, Ry, t)

subroutine to take an observation vector x and return Rx in observation space.

subroutine h (obsDim, nrhs, x, hx, t)

subroutine to take a full state vector x and return H(x) in observation space.

• subroutine ht (obsDim, nrhs, y, x, t)

subroutine to take an observation vector y and return  $x = H^T(y)$  in full state space.

• subroutine dist\_st\_ob (xp, yp, dis, t)

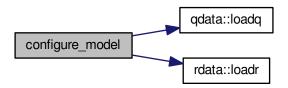
subroutine to compute the distance between the variable in the state vector and the variable in the observations

#### 5.1.1 Function/Subroutine Documentation

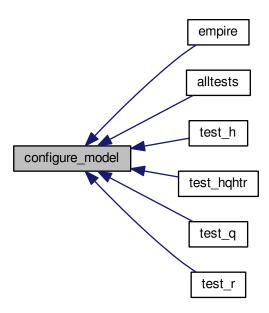
```
5.1.1.1 subroutine configure_model ( )
```

subroutine called initially to set up details and data for model specific functions Definition at line 30 of file model\_specific.f90.

Here is the call graph for this function:



Here is the caller graph for this function:



5.1.1.2 subroutine dist\_st\_ob ( integer, intent(in) *xp*, integer, intent(in) *yp*, real(kind=kind(1.0d0)), intent(out) *dis*, integer, intent(in) *t* )

subroutine to compute the distance between the variable in the state vector and the variable in the observations  $\text{Compute } \operatorname{dist}(x(xp),y(yp))$ 

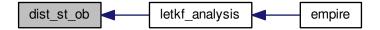
### Parameters

in	хр	the index in the state vector

in	ур	the index in the observation vector
out	dis	the distance between x(xp) and y(yp)
in	t	the current time index for observations

Definition at line 270 of file model\_specific.f90.

Here is the caller graph for this function:



5.1.1.3 subroutine h ( integer, intent(in) *obsDim*, integer, intent(in) *nrhs*, real(kind=rk), dimension(state\_dim,nrhs), intent(in) *x*, real(kind=rk), dimension(obsdim,nrhs), intent(out) *hx*, integer, intent(in) *t* )

subroutine to take a full state vector  $\mathbf{x}$  and return  $\mathbf{H}(\mathbf{x})$  in observation space.

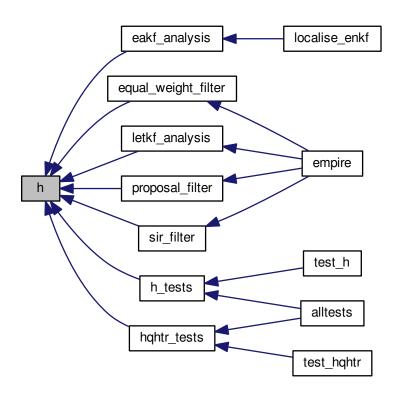
### Given x compute Hx

### **Parameters**

in	obsdim	the dimension of the observations
in	nrhs	the number of right hand sides
in	X	the input vectors in state space
out	hx	the resulting vector in observation space where $hx = Hx$
in	t	the timestep

Definition at line 224 of file model\_specific.f90.

Here is the caller graph for this function:



5.1.1.4 subroutine ht ( integer, intent(in) *obsDim*, integer, intent(in) *nrhs*, real(kind=rk), dimension(obsdim,nrhs), intent(in) *y*, real(kind=rk), dimension(state\_dim,nrhs), intent(out) *x*, integer, intent(in) *t* )

subroutine to take an observation vector y and return  $x = H^T(y)$  in full state space.

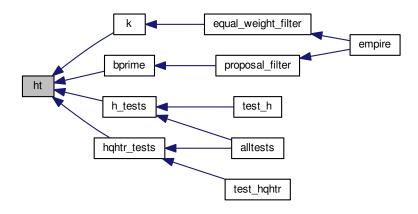
Given y compute  $x = H^T(y)$ 

### **Parameters**

in	obsdim	the dimension of the observations
in	nrhs	the number of right hand sides
in	у	the input vectors in observation space
out	X	the resulting vector in state space where $\mathbf{x} = \mathbf{H}^T \mathbf{y}$
in	t	the timestep

Definition at line 247 of file model\_specific.f90.

Here is the caller graph for this function:



5.1.1.5 subroutine q ( integer, intent(in) *nrhs*, real(kind=rk), dimension(state\_dim,nrhs), intent(in) *x*, real(kind=rk), dimension(state\_dim,nrhs), intent(out) *Qx* )

subroutine to take a full state vector x and return Qx in state space.

Given x compute Qx

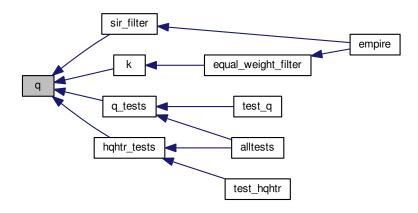
#### **Parameters**

in	nrhs	the number of right hand sides
in	X	the input vector
out	qx	the resulting vector where $Qx = Qx$

Definition at line 134 of file model\_specific.f90.



Here is the caller graph for this function:



5.1.1.6 subroutine qhalf ( integer, intent(in) *nrhs*, real(kind=rk), dimension(state\_dim,nrhs), intent(in) *x*, real(kind=rk), dimension(state\_dim,nrhs), intent(out) *Qx* )

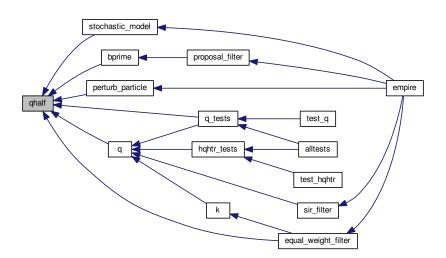
subroutine to take a full state vector x and return  $Q^{1/2}x$  in state space.

Given x compute  $Q^{\frac{1}{2}}x$ 

### **Parameters**

in	nrhs	the number of right hand sides
in	X	the input vector
out	qx	the resulting vector where $Qx = Q^{\frac{1}{2}}x$

Definition at line 159 of file model\_specific.f90.



5.1.1.7 subroutine r ( integer, intent(in) obsDim, integer, intent(in) nrhs, real(kind=rk), dimension(obsdim,nrhs), intent(in) y, real(kind=rk), dimension(obsdim,nrhs), intent(out) Ry, integer, intent(in) t)

subroutine to take an observation vector x and return Rx in observation space.

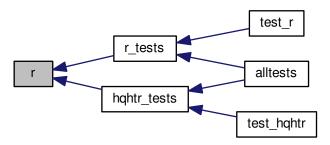
Given y compute Ry

#### **Parameters**

in	obsdim	the dimension of the observations
in	nrhs	the number of right hand sides
in	у	the input vector
out	ry	the resulting vectors where $Ry = Ry$
in	t	the timestep

Definition at line 179 of file model\_specific.f90.

Here is the caller graph for this function:



5.1.1.8 subroutine rhalf ( integer, intent(in) *obsDim*, integer, intent(in) *nrhs*, real(kind=rk), dimension(obsdim,nrhs), intent(in) *y*, real(kind=rk), dimension(obsdim,nrhs), intent(out) *Ry*, integer, intent(in) *t* )

subroutine to take an observation vector x and return Rx in observation space.

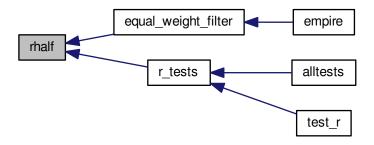
Given y compute  $R^{\frac{1}{2}}y$ 

#### **Parameters**

in	obsdim	the dimension of the observations
in	nrhs	the number of right hand sides
in	у	the input vector
out	ry	the resulting vector where $Ry = R^{\frac{1}{2}}y$
in	t	the timestep

Definition at line 201 of file model\_specific.f90.

Here is the caller graph for this function:



5.1.1.9 subroutine solve\_hqht\_plus\_r ( integer, intent(in) *obsdim*, real(kind=rk), dimension(obsdim), intent(in) *y*, real(kind=rk), dimension(obsdim), intent(out) *v*, integer, intent(in) *t* )

subroutine to take an observation vector y and return v in observation space.

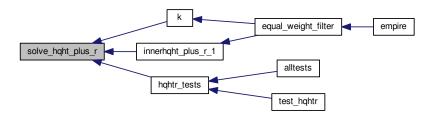
Given y find v such that  $(HQH^T + R)v = y$ 

#### **Parameters**

in	obsdim	the dimension of the observations
in	У	the input vector
out	v	the result where $v = (HQH^T + R)^{-1}y$
in	t	the timestep

Definition at line 114 of file model\_specific.f90.

Here is the caller graph for this function:



5.1.1.10 subroutine solve\_r ( integer, intent(in) *obsDim*, integer, intent(in) *nrhs*, real(kind=rk), dimension(obsdim,nrhs), intent(in) *y*, real(kind=rk), dimension(obsdim,nrhs), intent(out) *v*, integer, intent(in) *t* )

subroutine to take an observation vector y and return v in observation space.

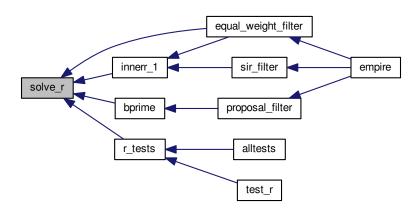
Given y find v such that Rv = y

#### **Parameters**

in	obsdim	the dimension of the observations
in	nrhs	the number of right hand sides
in	у	input vector
out	V	result vector where $v = R^{-1}y$
in	t	the timestep

Definition at line 72 of file model\_specific.f90.

Here is the caller graph for this function:



5.1.1.11 subroutine solve\_rhalf ( integer, intent(in) *obsdim*, integer, intent(in) *nrhs*, real(kind=rk), dimension(obsdim,nrhs), intent(in) *y*, real(kind=rk), dimension(obsdim,nrhs), intent(out) *v*, integer, intent(in) *t* )

subroutine to take an observation vector  $\boldsymbol{y}$  and return  $\boldsymbol{v}$  in observation space.

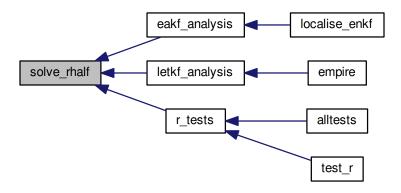
Given *y* find *v* such that  $R^{\frac{1}{2}}v = y$ 

### **Parameters**

in	obsdim	the dimension of the observations
in	nrhs	the number of right hand sides
in	у	input vector
out	V	result vector where $v = R^{-\frac{1}{2}}y$
in	t	the timestep

Definition at line 92 of file model\_specific.f90.

Here is the caller graph for this function:



# 5.2 src/controlers/pf\_control.f90 File Reference

### **Data Types**

- module pf\_control
  - module pf\_control holds all the information to control the the main program
- type pf\_control::pf\_control\_type

# 5.3 src/controlers/pf\_couple.f90 File Reference

# **Functions/Subroutines**

• program empire

the main program

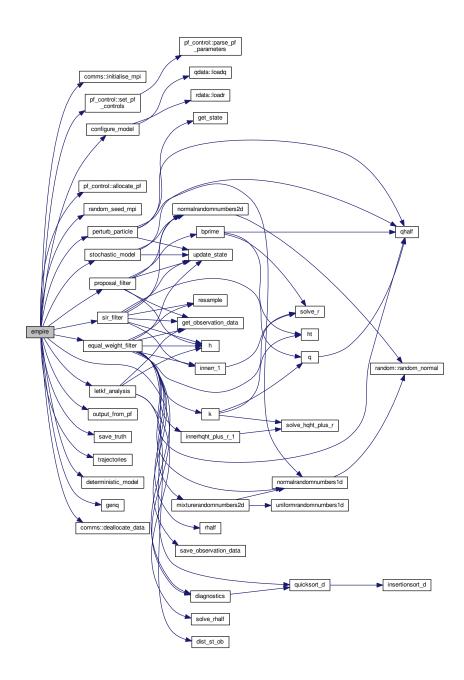
### 5.3.1 Function/Subroutine Documentation

5.3.1.1 program empire ( )

the main program

Definition at line 37 of file pf\_couple.f90.

Here is the call graph for this function:



# 5.4 src/controlers/pf\_parameters.dat File Reference

# 5.5 src/controlers/sizes.f90 File Reference

## **Data Types**

• module sizes

Module that stores the dimension of observation and state spaces.

### 5.6 src/data/Qdata.f90 File Reference

### **Data Types**

· module qdata

Module as a place to store user specified data for Q.

### 5.7 src/data/Rdata.f90 File Reference

### **Data Types**

· module rdata

Module to hold user supplied data for R observation error covariance matrix.

• module hqht\_plus\_r

## 5.8 src/DOC\_README.txt File Reference

# 5.9 src/filters/deterministic\_model.f90 File Reference

#### **Functions/Subroutines**

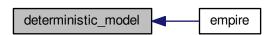
subroutine deterministic\_model
 subroutine to simply move the model forward in time one timestep PAB 21-05-2013

### 5.9.1 Function/Subroutine Documentation

5.9.1.1 subroutine deterministic\_model ( )

subroutine to simply move the model forward in time one timestep PAB 21-05-2013 Definition at line 32 of file deterministic\_model.f90.

Here is the caller graph for this function:



## 5.10 src/filters/eakf\_analysis.f90 File Reference

## **Functions/Subroutines**

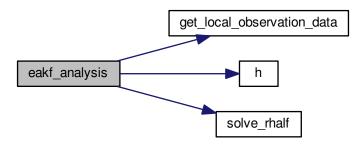
• subroutine eakf\_analysis (num\_hor, num\_ver, this\_hor, this\_ver, boundary, x, N, stateDim, obsDim, rho)

#### 5.10.1 Function/Subroutine Documentation

5.10.1.1 subroutine eakf\_analysis ( integer, intent(in) *num\_hor*, integer, intent(in) *num\_ver*, integer, intent(in) *this\_hor*, integer, intent(in) *this\_ver*, integer, intent(in) *boundary*, real(kind=rk), dimension(statedim,n), intent(inout) *x*, integer, intent(in) *N*, integer, intent(in) *stateDim*, integer, intent(in) *obsDim*, real(kind=rk), intent(in) *rho* )

Definition at line 27 of file eakf analysis.f90.

Here is the call graph for this function:



Here is the caller graph for this function:



### 5.11 src/filters/enkf specific.f90 File Reference

### **Functions/Subroutines**

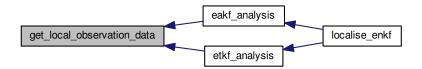
- subroutine h\_local (num\_hor, num\_ver, this\_hor, this\_ver, boundary, nrhs, stateDim, x, obsDim, y)
- subroutine solve\_rhalf\_local (num\_hor, num\_ver, this\_hor, this\_ver, boundary, nrhs, obsDim, y, v)
- subroutine get\_local\_observation\_data (num\_hor, num\_ver, this\_hor, this\_ver, boundary, obsDim, y)
- subroutine localise\_enkf (enkf\_analysis)

### 5.11.1 Function/Subroutine Documentation

5.11.1.1 subroutine get\_local\_observation\_data ( integer, intent(in) num\_hor, integer, intent(in) num\_ver, integer, intent(in) this\_hor, integer, intent(in) this\_ver, integer, intent(in) boundary, integer, intent(in) obsDim, real(kind=rk), dimension(obsdim), intent(out) y )

Definition at line 83 of file enkf\_specific.f90.

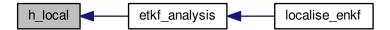
Here is the caller graph for this function:



5.11.1.2 subroutine h\_local ( integer, intent(in) num\_hor, integer, intent(in) num\_ver, integer, intent(in) this\_hor, integer, intent(in) this\_ver, integer, intent(in) boundary, integer, intent(in) nrhs, integer, intent(in) stateDim, real(kind=rk), dimension(statedim,nrhs), intent(in) x, integer, intent(in) obsDim, real(kind=rk), dimension(obsdim,nrhs), intent(out) y)

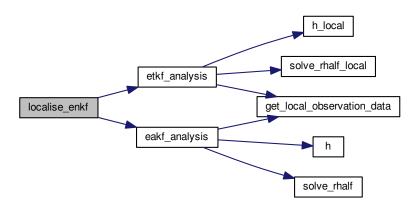
Definition at line 27 of file enkf\_specific.f90.

Here is the caller graph for this function:



5.11.1.3 subroutine localise\_enkf ( integer, intent(in) enkf\_analysis )

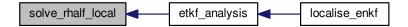
Definition at line 142 of file enkf\_specific.f90.



5.11.1.4 subroutine solve\_rhalf\_local ( integer, intent(in) num\_hor, integer, intent(in) num\_ver, integer, intent(in) this\_hor, integer, intent(in) this\_ver, integer, intent(in) boundary, integer, intent(in) nrhs, integer, intent(in) obsDim, real(kind=rk), dimension(obsdim,nrhs), intent(in) y, real(kind=rk), dimension(obsdim,nrhs), intent(out) v)

Definition at line 69 of file enkf\_specific.f90.

Here is the caller graph for this function:



# 5.12 src/filters/equivalent\_weights\_step.f90 File Reference

**Functions/Subroutines** 

• subroutine equal\_weight\_filter

subroutine to do the equivalent weights step

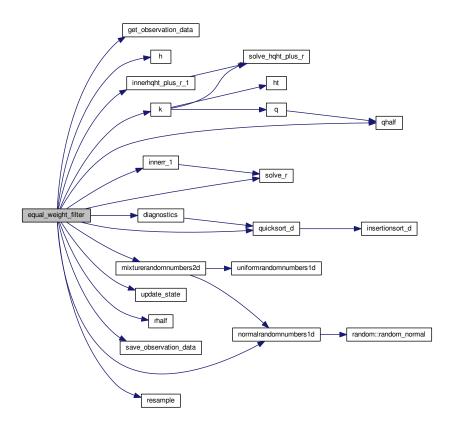
### 5.12.1 Function/Subroutine Documentation

5.12.1.1 subroutine equal\_weight\_filter ( )

subroutine to do the equivalent weights step

Definition at line 29 of file equivalent\_weights\_step.f90.

Here is the call graph for this function:



Here is the caller graph for this function:



# 5.13 src/filters/etkf\_analysis.f90 File Reference

### **Functions/Subroutines**

• subroutine etkf\_analysis (num\_hor, num\_ver, this\_hor, this\_ver, boundary, x, N, stateDim, obsDim, rho) subroutine to perform the ensemble transform Kalman filter

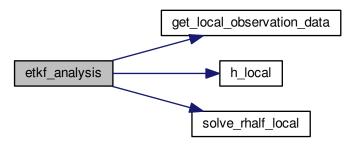
### 5.13.1 Function/Subroutine Documentation

5.13.1.1 subroutine etkf\_analysis ( integer, intent(in) num\_hor, integer, intent(in) num\_ver, integer, intent(in) this\_hor, integer, intent(in) this\_ver, integer, intent(in) boundary, real(kind=rk), dimension(statedim,n), intent(inout) x, integer, intent(in) N, integer, intent(in) stateDim, integer, intent(in) obsDim, real(kind=rk), intent(in) rho)

subroutine to perform the ensemble transform Kalman filter

Definition at line 34 of file etkf\_analysis.f90.

Here is the call graph for this function:



Here is the caller graph for this function:



# 5.14 src/filters/letkf\_analysis.f90 File Reference

### **Functions/Subroutines**

subroutine letkf\_analysis

subroutine to perform the ensemble transform Kalman filter as part of L-ETKF

### 5.14.1 Function/Subroutine Documentation

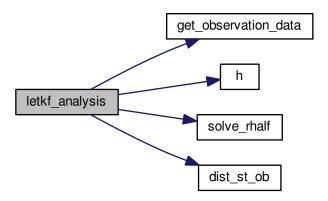
5.14.1.1 subroutine letkf\_analysis ( )

subroutine to perform the ensemble transform Kalman filter as part of L-ETKF

The observation

Definition at line 35 of file letkf\_analysis.f90.

Here is the call graph for this function:



Here is the caller graph for this function:



# 5.15 src/filters/proposal\_filter.f90 File Reference

### **Functions/Subroutines**

• subroutine proposal\_filter

Subroutine to perform nudging in the proposal step of EWPF.

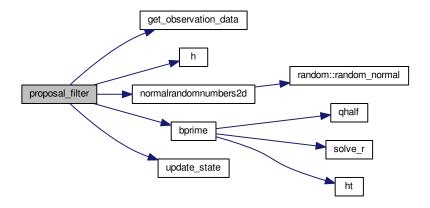
# 5.15.1 Function/Subroutine Documentation

5.15.1.1 subroutine proposal\_filter ( )

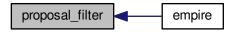
Subroutine to perform nudging in the proposal step of EWPF.

Definition at line 33 of file proposal\_filter.f90.

Here is the call graph for this function:



Here is the caller graph for this function:



# 5.16 src/filters/sir\_filter.f90 File Reference

### **Functions/Subroutines**

• subroutine sir\_filter

Subroutine to perform SIR filter (Sequential Importance Resampling)

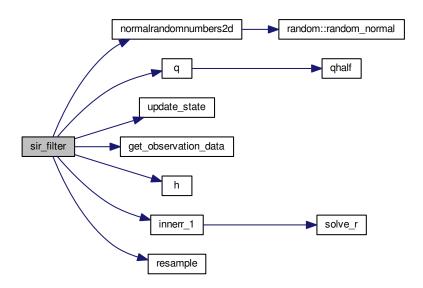
### 5.16.1 Function/Subroutine Documentation

5.16.1.1 subroutine sir\_filter ( )

Subroutine to perform SIR filter (Sequential Importance Resampling)

Definition at line 28 of file sir\_filter.f90.

Here is the call graph for this function:



Here is the caller graph for this function:



# 5.17 src/filters/stochastic\_model.f90 File Reference

### **Functions/Subroutines**

- subroutine stochastic\_model subroutine to simply move the model forward in time one timestep PAB 21-05-2013
- subroutine <a href="mailto:check\_scaling">check\_scaling</a> (x, fx, b, scales)

#### 5.17.1 Function/Subroutine Documentation

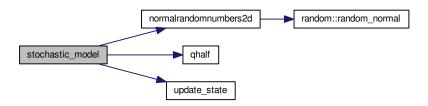
5.17.1.1 subroutine check\_scaling ( real(kind=rk), dimension(state\_dim), intent(in) x, real(kind=rk), dimension(state\_dim), intent(in) fx, real(kind=rk), dimension(state\_dim), intent(in) b, real(kind=rk), dimension(9), intent(inout) scales )

Definition at line 80 of file stochastic\_model.f90.

#### 5.17.1.2 subroutine stochastic\_model ( )

subroutine to simply move the model forward in time one timestep PAB 21-05-2013 Definition at line 32 of file stochastic\_model.f90.

Here is the call graph for this function:



Here is the caller graph for this function:



# 5.18 src/operations/gen\_rand.f90 File Reference

### **Functions/Subroutines**

- subroutine uniformrandomnumbers1d (minv, maxv, n, phi)

  generate one dimension of uniform random numbers
- subroutine normalrandomnumbers1d (mean, stdev, n, phi) generate one dimension of Normal random numbers
- subroutine normalrandomnumbers2d (mean, stdev, n, k, phi)
   generate two dimensional Normal random numbers
- subroutine mixturerandomnumbers1d (mean, stdev, ufac, epsi, n, phi, uniform) generate one dimensional vector drawn from mixture density
- subroutine mixturerandomnumbers2d (mean, stdev, ufac, epsi, n, k, phi, uniform) generate two dimensional vector, each drawn from mixture density
- subroutine random\_seed\_mpi (pfid)

Subroutine to set the random seed across MPI threads.

## 5.18.1 Function/Subroutine Documentation

5.18.1.1 subroutine mixturerandomnumbers1d ( real(kind=kind(1.0d0)), intent(in) *mean*, real(kind=kind(1.0d0)), intent(in) *stdev*, real(kind=kind(1.0d0)), intent(in) *ufac*, real(kind=kind(1.0d0)), intent(in) *epsi*, integer, intent(in) *n*, real(kind=kind(1.0d0)), dimension(n), intent(out) *phi*, logical, intent(out) *uniform* )

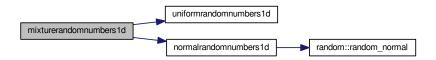
generate one dimensional vector drawn from mixture density

#### **Parameters**

		NA
in	mean	Mean of normal distribution
in	stdev	Standard deviation of normal distribution
in	ufac	half-width of uniform distribution that is centered on the mean
in	epsi	Proportion controlling mixture draw. if random_number > epsi then draw from
		uniform, else normal
in	n	size of output vector
out	phi	n dimensional mixture random numbers
out	uniform	True if mixture drawn from uniform. False if drawn from normal

Definition at line 90 of file gen\_rand.f90.

Here is the call graph for this function:



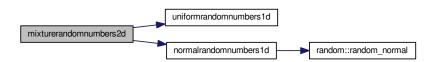
5.18.1.2 subroutine mixturerandomnumbers2d ( real(kind=kind(1.0d0)), intent(in) *mean*, real(kind=kind(1.0d0)), intent(in) *stdev*, real(kind=kind(1.0d0)), intent(in) *ufac*, real(kind=kind(1.0d0)), intent(in) *epsi*, integer, intent(in) *n*, integer, intent(in) *k*, real(kind=kind(1.0d0)), dimension(n,k), intent(out) *phi*, logical, dimension(k), intent(out) *uniform* )

generate two dimensional vector, each drawn from mixture density

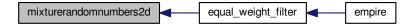
#### **Parameters**

in	mean	Mean of normal distribution
in	stdev	Standard deviation of normal distribution
in	ufac	half-width of uniform distribution that is centered on the mean
in	epsi	Proportion controlling mixture draw. if random_number > epsi then draw from
		uniform, else normal
in	n	first dimension of output vector
in	k	second dimension of output vector
out	phi	n,k dimensional mixture random numbers
out	uniform	k dimensional logical with uniform(i) True if phi(:,i) drawn from uniform. False if
		drawn from normal

Definition at line 125 of file gen\_rand.f90.



Here is the caller graph for this function:



5.18.1.3 subroutine normalrandomnumbers1d ( real(kind=rk), intent(in) *mean,* real(kind=rk), intent(in) *stdev,* integer, intent(in) *n,* real(kind=rk), dimension(n), intent(out) *phi* )

generate one dimension of Normal random numbers

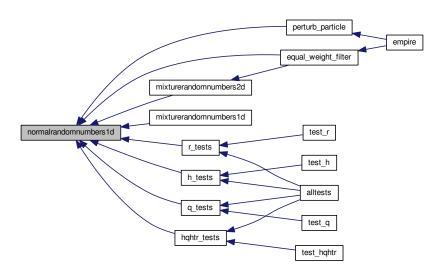
### **Parameters**

in	n	n size of output vector
in	mean	mean mean of normal distribution
in	stdev	stdev Standard Deviation of normal distribution
out	phi	phi n dimensional normal random numbers

Definition at line 43 of file gen\_rand.f90.



Here is the caller graph for this function:



5.18.1.4 subroutine normalrandomnumbers2d ( real(kind=rk), intent(in) *mean,* real(kind=rk), intent(in) *stdev,* integer, intent(in) *n,* integer, intent(in) *k,* real(kind=rk), dimension(n,k), intent(out) *phi* )

generate two dimensional Normal random numbers

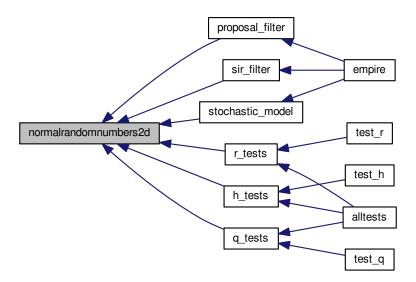
### **Parameters**

in	n	n first dimension of output vector
in	k	k second dimension of output vector
in	mean	mean mean of normal distribution
in	stdev	stdev Standard Deviation of normal distribution
out	phi	phi n,k dimensional normal random numbers

Definition at line 60 of file gen\_rand.f90.



Here is the caller graph for this function:



5.18.1.5 subroutine random\_seed\_mpi ( integer, intent(in) pfid )

Subroutine to set the random seed across MPI threads.

### **Parameters**

	1	
in	pfid	The process identifier of the MPI process

Definition at line 151 of file gen\_rand.f90.

Here is the caller graph for this function:



5.18.1.6 subroutine uniformrandomnumbers1d ( real(kind=rk), intent(in) *minv*, real(kind=rk), intent(in) *maxv*, integer, intent(in) *n*, real(kind=rk), dimension(n), intent(out) *phi* )

generate one dimension of uniform random numbers

#### **Parameters**

in	n	n size of output vector
in	minv	minv minimum value of uniform distribution
in	maxv	maxv maximum value of uniform distribution
out	phi	phi n dimensional uniform random numbers

Definition at line 28 of file gen rand.f90.

Here is the caller graph for this function:



# 5.19 src/operations/operator\_wrappers.f90 File Reference

### **Functions/Subroutines**

• subroutine k (y, x)

Subroutine to apply K to a vector y in observation space where  $K := QH^T(HQH^T + R)^{-1}$ .

• subroutine innerr\_1 (y, w)

subroutine to compute the inner product with  $R^{-1}$ 

• subroutine innerhqht\_plus\_r\_1 (y, w)

subroutine to compute the inner product with  $(HQH^T + R)^{-1}$ 

• subroutine bprime (y, x, QHtR\_1y, normaln, betan)

subroutine to calculate nudging term and correlated random errors efficiently

#### 5.19.1 Function/Subroutine Documentation

5.19.1.1 subroutine bprime ( real(kind=rk), dimension(obs\_dim,pf%count), intent(in) y, real(kind=rk), dimension(state\_dim,pf%count), intent(out) x, real(kind=rk), dimension(state\_dim,pf%count), intent(out) QHtR\_1y, real(kind=rk), dimension(state\_dim,pf%count), intent(in) normaln, real(kind=rk), dimension(state\_dim,pf%count), intent(out) betan )

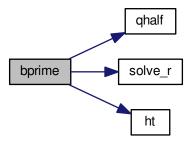
subroutine to calculate nudging term and correlated random errors efficiently

### **Parameters**

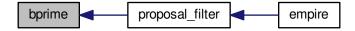
in	у	(obs_dim,pf%count) vectors of innovations $y - H(x^{n-1})$
out	X	(state_dim,pf%count) vectors of $\rho H^T R^{-1}[y - H(x^{n-1})]$
out	QHtR_1y	(state_dim,pf%count) vectors of $\rho QH^TR^{-1}[y-H(x^{n-1})]$
in	normaln	(state_dim,pf%count) uncorrelated random vectors such that normaln(:,i) ~
		$\mathscr{N}(0,I)$
out	betan	(state_dim,pf%count) correlated random vectors such that betan(:,i) ~
		$\mathscr{N}(0,Q)$

Definition at line 155 of file operator\_wrappers.f90.

Here is the call graph for this function:



Here is the caller graph for this function:



5.19.1.2 subroutine innerhqht\_plus\_r\_1 ( real(kind=rk), dimension(obs\_dim), intent(in) y, real(kind=rk), intent(out) w)

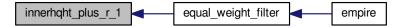
subroutine to compute the inner product with  $(\boldsymbol{H}\boldsymbol{Q}\boldsymbol{H}^T + \boldsymbol{R})^{-1}$ 

### **Parameters**

iı	1	У	vector in observation space
ou		W	scalar with value $y^T R^{-1} y$

Definition at line 91 of file operator\_wrappers.f90.





5.19.1.3 subroutine innerr\_1 ( real(kind=rk), dimension(obs\_dim,pf%count), intent(in) y, real(kind=rk), dimension(pf%count), intent(out) w )

subroutine to compute the inner product with  $R^{-1}$ 

#### **Parameters**

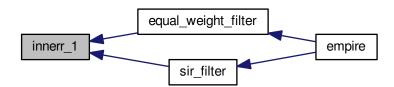
	in	У	multiple vectors in observation space (pf%count of them)
Ī	out	W	multiple scalars (pf%count) where w(i) has the value $y(:,i)^T R^{-1} y(:,i)$

Definition at line 65 of file operator\_wrappers.f90.

Here is the call graph for this function:



Here is the caller graph for this function:



5.19.1.4 subroutine k ( real(kind=rk), dimension(obs\_dim,pf%count), intent(in) y, real(kind=rk), dimension(state\_dim,pf%count), intent(out) x )

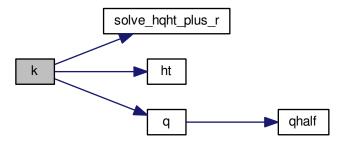
Subroutine to apply K to a vector  $\mathbf{y}$  in observation space where  $K := QH^T(HQH^T + R)^{-1}$ .

#### **Parameters**

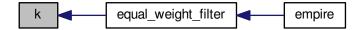
in	у	vector in observation space
out	X	vector in state space

Definition at line 32 of file operator\_wrappers.f90.

Here is the call graph for this function:



Here is the caller graph for this function:



# 5.20 src/operations/perturb\_particle.f90 File Reference

## **Functions/Subroutines**

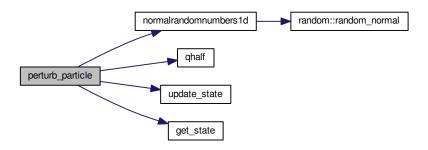
- subroutine perturb\_particle (x)
  - Subroutine to perturb state vector with normal random vector drawn from  $\mathcal{N}(0,Q)$ .
- subroutine update\_state (state, fpsi, kgain, betan)

Subroutine to update the state.

#### 5.20.1 Function/Subroutine Documentation

5.20.1.1 subroutine perturb\_particle ( real(kind=rk), dimension(state\_dim), intent(inout) x )

Subroutine to perturb state vector with normal random vector drawn from  $\mathcal{N}(0,Q)$ . Definition at line 30 of file perturb\_particle.f90.



Here is the caller graph for this function:



5.20.1.2 subroutine update\_state ( real(kind=rk), dimension(state\_dim), intent(out) *state*, real(kind=rk), dimension(state\_dim), intent(in) *fpsi*, real(kind=rk), dimension(state\_dim), intent(in) *kgain*, real(kind=rk), dimension(state\_dim), intent(inout) *betan* )

Subroutine to update the state.

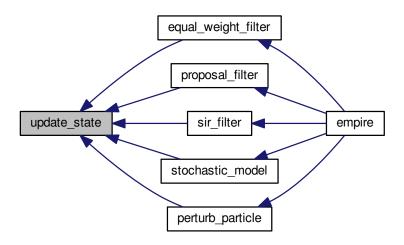
This can be changed for the specific model if it needs to be

#### **Parameters**

in	fpsi	deterministic model update $f(x^{n-1})$
in	kgain	nudging term
in,out	betan	Stochastic term
out	state	The updated state vector

Definition at line 95 of file perturb\_particle.f90.

Here is the caller graph for this function:



# 5.21 src/operations/resample.f90 File Reference

## **Functions/Subroutines**

• subroutine resample

Subroutine to perform Universal Importance Resampling.

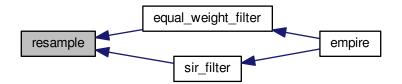
#### 5.21.1 Function/Subroutine Documentation

## 5.21.1.1 subroutine resample ( )

Subroutine to perform Universal Importance Resampling.

Definition at line 28 of file resample.f90.

Here is the caller graph for this function:



## 5.22 src/tests/alltests.f90 File Reference

#### **Functions/Subroutines**

• program alltests

program to run all tests of user specific functions

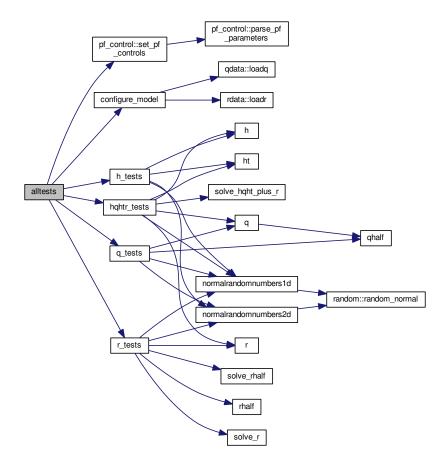
#### 5.22.1 Function/Subroutine Documentation

#### 5.22.1.1 program alltests ( )

program to run all tests of user specific functions

Definition at line 31 of file alltests.f90.

Here is the call graph for this function:



# 5.23 src/tests/test\_h.f90 File Reference

## **Functions/Subroutines**

· program test\_h

program to run tests of user supplied observation operator

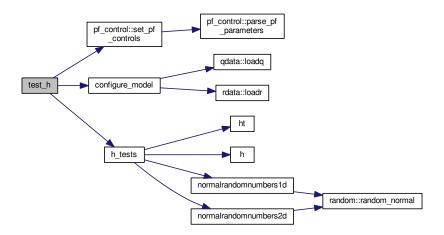
## 5.23.1 Function/Subroutine Documentation

#### 5.23.1.1 program test\_h ( )

program to run tests of user supplied observation operator

Definition at line 31 of file test\_h.f90.

Here is the call graph for this function:



# 5.24 src/tests/test\_hqhtr.f90 File Reference

#### **Functions/Subroutines**

• program test\_hqhtr

program to run tests of user supplied linear solve

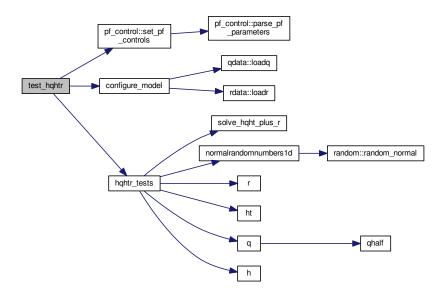
#### 5.24.1 Function/Subroutine Documentation

5.24.1.1 program test\_hqhtr ( )

program to run tests of user supplied linear solve

$$(HQH^T + R)^{-1}$$

Definition at line 33 of file test\_hqhtr.f90.



# 5.25 src/tests/test\_q.f90 File Reference

## **Functions/Subroutines**

program test\_q

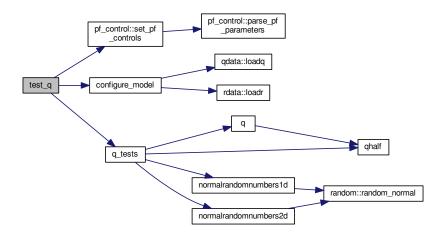
program to run tests of user supplied model error covariance matrix

## 5.25.1 Function/Subroutine Documentation

# 5.25.1.1 program test\_q ( )

program to run tests of user supplied model error covariance matrix Definition at line 31 of file test\_q.f90.

Here is the call graph for this function:



# 5.26 src/tests/test\_r.f90 File Reference

#### **Functions/Subroutines**

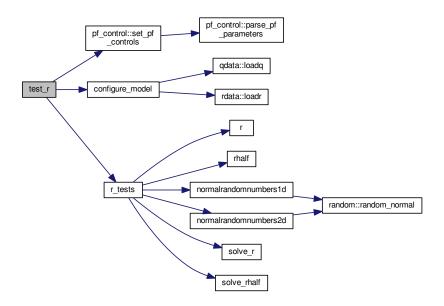
program test\_r

program to run all tests of user supplied observation error covariance matrix/

#### 5.26.1 Function/Subroutine Documentation

## 5.26.1.1 program test\_r ( )

program to run all tests of user supplied observation error covariance matrix/ Definition at line 31 of file test\_r.f90.



## 5.27 src/tests/tests.f90 File Reference

#### **Functions/Subroutines**

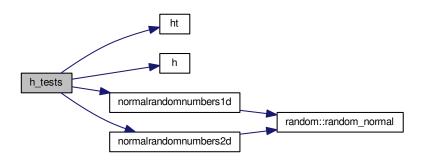
- subroutine h\_tests ()
- subroutine r\_tests ()
- subroutine q\_tests ()
- subroutine hqhtr\_tests ()

## 5.27.1 Function/Subroutine Documentation

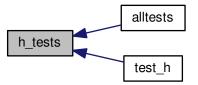
#### 5.27.1.1 subroutine h\_tests ( )

These are some tests to check that the observation operator is implemented correctly Definition at line 27 of file tests.f90.

Here is the call graph for this function:



Here is the caller graph for this function:

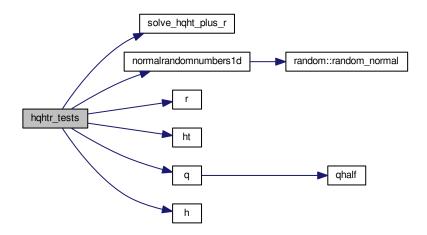


# 5.27.1.2 subroutine hqhtr\_tests ( )

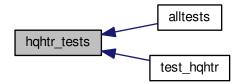
These are some tests to check that the linear solve operator is implemented correctly

This should check the operation  $(HQH^T + R)^{-1}$  is working

Definition at line 876 of file tests.f90.



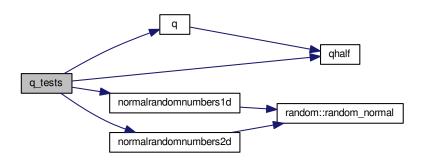
Here is the caller graph for this function:



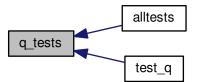
# 5.27.1.3 subroutine q\_tests ( )

These are some tests to check that the model error covariance matrix is implemented correctly Definition at line 672 of file tests.f90.

Here is the call graph for this function:

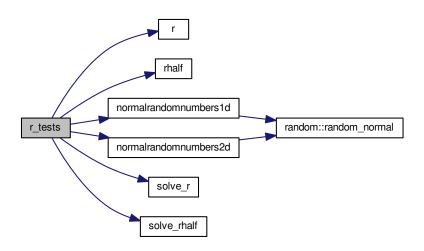


Here is the caller graph for this function:

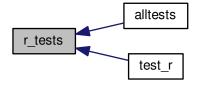


## 5.27.1.4 subroutine r\_tests ( )

These are some tests to check that the observation error covariance matrix is implemented correctly Definition at line 254 of file tests.f90.



Here is the caller graph for this function:



# 5.28 src/utils/comms.f90 File Reference

# **Data Types**

• module comms

Module containing EMPIRE coupling data.

# 5.29 src/utils/data\_io.f90 File Reference

## **Functions/Subroutines**

- subroutine get\_observation\_data (y)
   Subroutine to read observation from a file
   Uses pftimestep to determine which observation to read.
- subroutine save\_observation\_data (y)

Subroutine to save observation to a file Uses pftimestep to determine which observation to save.

• subroutine save\_truth (x)

Subroutine to save truth to a file

subroutine output\_from\_pf

subroutine to ouput data from the filter

• subroutine save\_state (state, filename)

subroutine to save the state vector to a named file as an unformatted fortran file

• subroutine get\_state (state, filename)

subroutine to write the state vector to a named file as an unformatted fortran file

#### 5.29.1 Function/Subroutine Documentation

5.29.1.1 subroutine get\_observation\_data ( real(kind=rk), dimension(obs\_dim), intent(out) y )

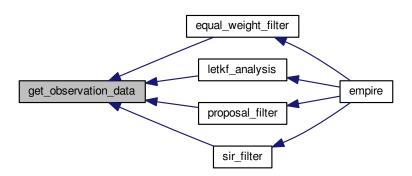
Subroutine to read observation from a file
Uses pftimestep to determine which observation to read.

#### **Parameters**

	I	
out	V	The observation
	,	

Definition at line 32 of file data\_io.f90.

Here is the caller graph for this function:



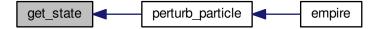
5.29.1.2 subroutine get\_state ( real(kind=rk), dimension(state\_dim), intent(out) state, character(14), intent(in) filename )

subroutine to write the state vector to a named file as an unformatted fortran file

#### **Parameters**

out	state	the state vector
in	filename	the name of the file to write the state vector in

Definition at line 283 of file data\_io.f90.



5.29.1.3 subroutine output\_from\_pf ( )

subroutine to ouput data from the filter

Definition at line 124 of file data\_io.f90.

Here is the caller graph for this function:



5.29.1.4 subroutine save\_observation\_data ( real(kind=rk), dimension(obs\_dim), intent(in) y )

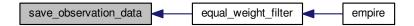
Subroutine to save observation to a file
Uses pftimestep to determine which observation to save.

#### **Parameters**

in	у	The observation

Definition at line 60 of file data\_io.f90.

Here is the caller graph for this function:



5.29.1.5 subroutine save\_state ( real(kind=rk), dimension(state\_dim), intent(in) state, character(14), intent(in) filename )

subroutine to save the state vector to a named file as an unformatted fortran file

#### **Parameters**

in	state	the state vector
in	filename	the name of the file to save the state vector in

Definition at line 257 of file data io.f90.

5.29.1.6 subroutine save\_truth ( real(kind=rk), dimension(state\_dim), intent(in) x )

Subroutine to save truth to a file

#### **Parameters**

in	X	The state vector

Definition at line 98 of file data\_io.f90.

Here is the caller graph for this function:



# 5.30 src/utils/diagnostics.f90 File Reference

# **Functions/Subroutines**

- · subroutine diagnostics
  - Subroutine to give output diagnositics such as rank histograms and trajectories.
- subroutine trajectories

subroutine to output trajectories

## 5.30.1 Function/Subroutine Documentation

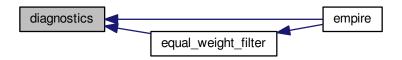
#### 5.30.1.1 subroutine diagnostics ( )

Subroutine to give output diagnositics such as rank histograms and trajectories.

Definition at line 31 of file diagnostics.f90.

Here is the call graph for this function:



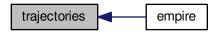


## 5.30.1.2 subroutine trajectories ( )

subroutine to output trajectories

Definition at line 203 of file diagnostics.f90.

Here is the caller graph for this function:



# 5.31 src/utils/genQ.f90 File Reference

## **Functions/Subroutines**

· subroutine genq

Subroutine to estimate Q from a long model run.

## 5.31.1 Function/Subroutine Documentation

# 5.31.1.1 subroutine genq ( )

Subroutine to estimate Q from a long model run.

Definition at line 28 of file genQ.f90.

Here is the caller graph for this function:



# 5.32 src/utils/histogram.f90 File Reference

# **Data Types**

• module histogram\_data

Module to control what variables are used to generate rank histograms.

# 5.33 src/utils/quicksort.f90 File Reference

## **Functions/Subroutines**

- recursive subroutine quicksort\_d (a, na)
   subroutine to sort using the quicksort algorithm
- subroutine insertionsort\_d (A, nA)

subroutine to sort using the insertionsort algorithm

#### 5.33.1 Function/Subroutine Documentation

5.33.1.1 subroutine insertionsort\_d ( real(kind=kind(1.0d0)), dimension(na), intent(inout) A, integer, intent(in) nA)

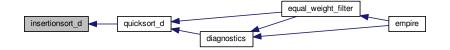
subroutine to sort using the insertionsort algorithm

#### **Parameters**

in,out	а	array of doubles to be sorted
in	na	dimension of array a

Definition at line 86 of file quicksort.f90.

Here is the caller graph for this function:



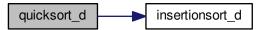
5.33.1.2 recursive subroutine quicksort\_d ( real(kind=kind(1.0d0)), dimension(na), intent(inout) a, integer, intent(in) na ) subroutine to sort using the quicksort algorithm

#### **Parameters**

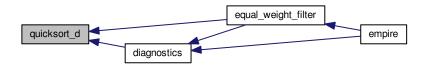
in,out	а	array of doubles to be sorted
in	na	dimension of array a

Definition at line 9 of file quicksort.f90.

Here is the call graph for this function:



Here is the caller graph for this function:



# 5.34 src/utils/random\_d.f90 File Reference

# **Data Types**

• module random

A module for random number generation from the following distributions:

# Index

allocate_data	deterministic_model.f90, 46
comms, 10	deterministic_model.f90
allocate_pf	deterministic_model, 46
pf_control, 15	diagnostics
alltests	diagnostics.f90, 78
alltests.f90, 67	diagnostics.f90
alltests.f90	diagnostics, 78
alltests, 67	trajectories, 79
	dist_st_ob
bin_prob	model_specific.f90, 36
random, 26	dp
bprime	random, 31
operator_wrappers.f90, 61	
	eakf_analysis
check_scaling	eakf_analysis.f90, 47
stochastic_model.f90, 54	eakf_analysis.f90
comms, 9	eakf_analysis, 47
allocate_data, 10	efac
cpl_mpi_comm, 10	pf_control::pf_control_type, 19
deallocate_data, 10	empire
gblcount, 10	pf_couple.f90, 44
gbldisp, 10	enkf_specific.f90
initialise_mpi, 10	get_local_observation_data, 47
mype_id, 11	h_local, 48
myrank, 11	localise_enkf, 48
npfs, 11	solve_rhalf_local, 48
nproc, 11	equal_weight_filter
pf_mpi_comm, 11	equivalent_weights_step.f90, 49
pfrank, 11	equivalent_weights_step.f90
configure_model	equal_weight_filter, 49
model_specific.f90, 35	etkf_analysis
count	etkf_analysis.f90, 50
pf_control::pf_control_type, 19	etkf analysis.f90
couple root	etkf_analysis, 50
pf_control::pf_control_type, 19	_ , ,
cpl_mpi_comm	gblcount
comms, 10	comms, 10
,	gbldisp
data_io.f90	comms, 10
get_observation_data, 76	gen_data
get state, 76	pf_control::pf_control_type, 19
output_from_pf, 77	gen_q
save_observation_data, 77	pf_control::pf_control_type, 19
save state, 77	gen_rand.f90
save truth, 78	mixturerandomnumbers1d, 55
deallocate_data	mixturerandomnumbers2d, 57
comms, 10	normalrandomnumbers1d, 58
deallocate_pf	normalrandomnumbers2d, 59
pf_control, 15	random_seed_mpi, 60
deterministic_model	uniformrandomnumbers1d, 60
dotorminiono_moder	dimoninandonnanders id, 00

genq, 79 genQ genQ get_local_observation_data enkf_specific.190, 47 get_observation_data data_io.190, 76 get_state data_io.190, 76 get_state data_io.190, 76 flocal enkf_specific.190, 37 h_local enkf_specific.190, 48 h_tests tests.190, 71 histogram_data, 11 kill_histogram_data, 12 rank_hist_lust_12 rank_hist_lust_12 rank_hist_lust_12 rank_hist_lust_12 rank_hist_lotor, 13 hqhtr_lactor, 13 kill_hethr, 13 load hiptr, 13 hqhtr_factor hqht_plus_r, 14 solve_hqht_plus_r, 42 solve_r, 42 solv	genQ.f90	rdata, 32
genQ.f90, 79 get_local_observation_data enkt_specific.f90, 47 get_lobservation_data data_io.f90, 76 get_state data_io.f90, 76 get_state data_io.f90, 76 formalizer data data_io.f90, 76 get_state data_io.f90, 76 formalizer data data_io.f90, 76 formalizer data formalizer data data_io.f90, 76 formalizer data formalizer d	genq, 79	
get_local_observation_data enkl_specific.190, 47 get_observation_data data_io.190, 76 get_state data_io.190, 76 get_state data_io.190, 76  form model_specific.190, 37 h_local enkl_specific.190, 48 h_tests tests.190, 71 histogram_data, 11 kill_histogram_data, 12 rank_hist_list, 12 rank_hist_list, 12 rank_hist_lusr_12 rhl_n_, 12 rhl_n_n_, 12 rhl_n_losal hight_flactor, 13 kill_hipt_gram_data, 12 load_hiptt, 13 hother_factor hight_plus_r_, 13 hight_rests  hight_restriction_high_plus_r_, 14  hight_plus_r_, 12  hight_plus_r_, 12  hight_plus_r_, 12  hight_plus_r_, 13 hig		
enkf_specific.f90, 47 get_observation_data data_io.f90, 76 get_state data_io.f90, 76 get_state data_io.f90, 76  from model_specific.f90, 37 h_local enkf_specific.f90, 48 h_tests tests.f90, 71 histogram_data, 12 load_histogram_data, 12 load_histogram_data histogram_data, 12 load_histogram_data histogram_data histogram_data loadr rdata, 23 loadr rdata, 23 loadr rdata, 32 loadlise_enkf enkf_specific.f90, 55 mixturerandomnumbers1d gen_rand.f90, 57 mixturerandomnumbers2d gen_rand.f90, 57 mixturerandom	•	
get_observation_data	<del>•</del> — — — —	_ •
data_io.f90, 76   letk_analysis, 51   lingamma random, 26   load_histogram_data, 12   load_hist logram_data, 12   load_hist load_load_data, 23   loadr_ristala, 12   load_hist load_load_data, 12   load_hist load_load_load_load_load_l	— ·	
get_state     data_io.f90, 76  h model_specific.f90, 37 h_local enkf_specific.f90, 48 h_tests tests.f90, 71 histogram_data, 12 load_histogram_data, 12 load_histogram_data, 12 load_histogram_data, 12 rank_hist_list, 12 rank_hist_list, 12 rank_hist_list, 12 rank_hist_lours, 12 rhl_n, 12 rhl_n, 12 rhl_n, 12 rhl_n, 13 hqhtr_factor, 13 kill_hqhtr, 13 load_hqhtr, 13 hqhtr_factor hqht_plus_r, 13 hqhtr_fasts tests.f90, 72 ht model_specific.f90, 38 human_readable pf_control:pf_control_type, 19 initialise_mpi comms, 10 innerhqht_plus_r_1 operator_wrappers.f90, 63 kep pf_control:pf_control_type, 20 kill_histogram_data histogram_data histogram_data histogram_data histogram_data histogram_data histogram_data, 12 load_hqhtr hqht_plus_r, 13 loadq qdata, 23 loadr rdata, 22 localise_enkt enkf_specific.f90, 48 mean pf_control:pf_control_type, 20 mixturerandomnumbers1d gen_rand.f90, 55 mixturerandomnumbers2d gen_rand.f90, 57 model_specific.f90, 35 configure_model, 35 dist_st_ob, 36 h, 37 th, 38 q, 39 qhalf, 40 r, 40 rhalf, 41 solve_hqht_plus_r, 42 solve_r, 42 solve		
data_io.f90, 76  h model_specific.f90, 37 h_local enkf_specific.f90, 48 h_tests tests.f90, 71 histogram_data, 11 kill_histogram_data, 12 load_histogram_data, 12 load_histogram_data, 12 load_histogram_data, 12 rank_hist_list, 12 rank_hist_list, 12 rank_hist_nums, 12 rhl_n, 12 rhn_n, 12 hqht_plus_r, 13 hqhtr_factor, 13 kill_hqhtr, 13 load_hqhtr, 13 loadir rdata, 32 loadis-penkfenkfenkfenkfenkfenkfenkfenkfenkfenkf		<del>-</del>
nodel_specific.f90, 37 h_local enkf_specific.f90, 48 h_tests tests.f90, 71 histogram_data, 12 load_hqhtr histogram_data, 12 load_hqhtr hqht_plus_r, 13 load q qdata, 23 loadr rdata, 32 loadise_enkf enkf_specific.f90, 48  mean pf_control:pf_control_type, 20 mixturerandomnumbers 1d gen_rand.f90, 57 model_specific.f90, 38 human_readable pf_control::pf_control_type, 19 initialise_mpi comms, 10 innerhqht_plus_r_1 operator_wrappers.f90, 63 insertionsort_d quicksort_f90, 80  k operator_wrappers.f90, 63 keep pf_control::pf_control_type, 20 mixturerandomnumbers 2d gen_rand.f90, 57 model_specific.f90, 35 configure_model, 35 dist_st_ob, 36 h, 37 h, 38 q, 39 qhalf, 40 r, 40 rhalf, 41 solve_hqht_plus_r, 42 solve_r, 42 solve_r, 42 solve_r, 42 solve_rhalf, 43 mype_id comms, 10 innerhqht_plus_r1 operator_wrappers.f90, 63 insertionsort_d quicksort.f90, 80  k operator_wrappers.f90, 63 keep pf_control::pf_control_type, 20 kill_histogram_data histogram_data histogram_		Ingamma
h model_specific.f90, 37 h_local enkl_specific.f90, 48 h_tests tests.f90, 71 histogram_data, 12 kill_histogram_data, 12 load_hiptir hqht_plus_r, 13 loadq qdata, 23 loadr rdata, 23 loadq qdata, 23 loadr rdata, 32 loadr rdata, 32 loadr rdata, 32 localise_enkf enkl_specific.f90, 48  mean file_flus_r, 13 hqht_flus_r, 13 hqht_flus_r, 13 hqht_flactor, 13 hqht_flactor, 13 hqht_flests tests.f90, 72 ht model_specific.f90, 38 human_readable pf_control::pf_control_type, 19 initialise_mpi comms, 10 innerhqht_plus_r_1 operator_wrappers.f90, 63 keep pf_control::pf_control_type, 20 mfac  k pf_control::pf_control_type, 19 initialise_mpi comms, 10 innerhqht_plus_fl operator_wrappers.f90, 63 keep pf_control::pf_control_type, 20 nfac k pf_control::pf_control_type, 20 nfac comms, 11 nproc kill_hqhtr hqht_plus_r, 13 kill qdata, 23 loadr rdata, 22 localise_enkf enkl_specific.f90, 48  mean rdata, 32 localise_enkf enkl_specific.f90, 48  mean fdcalise_enkf enkl_specific.f90, 48  mean fdcalise_enkf enkl_specific.f90, 48  mean fdcalise_enkf enkl_specific.f90, 48  mean fdata, 32 localise_enkf enkl_specific.f90, 58  mixturerandomnumbers1d gen_rand.f90, 58  normalrandomnumbers2d gen_rand.f90, 58  normalrandomnumbers2d gen_rand.f90, 58  normalrandomnu	data_io.f90, 76	random, 26
model_specific.f90, 37 h_local enkf_specific.f90, 48 h_tests tests.f90, 71 histogram_data, 12 load_histogram_data, 12 load_histogram_data, 12 load_histogram_data, 12 load_histogram_data, 12 rank_hist_list, 12 rank_hist_nums, 12 rhl_n, 12 rhl_n, 12 rhl_n, 12 hqht_plus_r, 13 hqhtr_factor, 13 kill_hqhtr, 13 load_hqhtr, 13 hqhtr_factor hqht_plus_r, 13 hqhtr_fests tests.f90, 72 ht model_specific.f90, 38 human_readable pf_control::pf_control_type, 19 initalise_mpi comms, 10 innerhqht_plus_r, 1 operator_wrappers.f90, 63 insertionsort_d quicksort.f90, 80  k operator_wrappers.f90, 63 keep pf_control::pf_control_type, 20 kill_histogram_data histogram_data histogram_data, 12 kill_qdata, 23 load hqhtr hqht_plus_r, 13 load qdata, 23 loadi hqtr hqht_plus_r, 13 load rdata, 22 localise_enkf enkf_specific.f90, 48 enkf_specific.f90, 58 mixturerandomnumbers2d gen_rand.f90, 55 normalrandomnumbers d gen_rand.f		load_histogram_data
h_local		histogram_data, 12
enkf_specific.f90, 48 h_tests tests.f90, 71 histogram_data, 11 kill_histogram_data, 12 load_histogram_data, 12 rank_hist_list, 12 rank_hist_list, 12 rank_hist_list, 12 rank_hist_nums, 12 rhl_n, 12 hqht_plus_r, 13 hqhtr_factor, 13 kill_hqhtr, 13 load_hqhtr, 13 hqhtr_factor hqht_plus_r, 13 hqhtr_fests tests.f90, 72 ht model_specific.f90, 38 human_readable pf_control::pf_control_type, 19 initi pf_control::pf_control_type, 19 initialise_mpi comms, 10 innerrhqht_plus_r_1 operator_wrappers.f90, 63 insertionsort_d quicksort.f90, 80  k operator_wrappers.f90, 63 keep pf_control::pf_control_type, 20 kill_histogram_data histogram_data histogram_data killq qdata, 23 loadr rdata, 23 loadr rdata, 32 localise_enkf enkf_specific.f90, 48  mean pf_control::pf_control_type, 20 mixturerandomnumbers1d gen_rand.f90, 55 mixturerandomnumbers2d gen_rand.f90, 55 mixturerandomnumbers1d gen_rand.f90, 55 mixturerandomnumbers1d gen_rand.f90, 56 mixturerandomnumbers1d gen_rand.f90, 56 mixturerandomnumbers1d gen_rand.f90, 56 mixturerandomnumbers1d gen_rand.f90, 58 normalrandomnumbers1d gen_rand.f90, 59 npfs comms, 11 nproc comms, 11 nudgefac	— ·	load_hqhtr
h_tests tests.f90, 71 histogram_data, 11 kill_histogram_data, 12 load_histogram_data, 12 rank_hist_list, 12 rank_hist_nums, 12 rhl_n, 12 hqht_plus_r, 13 hqhtr_factor, 13 kill_hqhtr, 13 load_hqhtr, 13 hqhtr_tests tests.f90, 72 ht model_specific.f90, 38 human_readable pf_control::pf_control_type, 19 initialise_mpi comms, 10 innerhqht_plus_r_1 operator_wrappers.f90, 63 insertionsort_d quicksort.f90, 80 kill_hqhtr hqht_plus_r, 13 kill_hqhtr hqht_plus_r_f, 13 roperator_wrappers.f90, 63 keep pf_control::pf_control_type, 20 kill_hqhtr hqht_plus_r, 13 kill_hqhtr hqht_plus_r, 13 roperator_wrappers.f90, 63 kill_hqhtr hqht_plus_r, 13 kill_qdata, 23 loadr rdata, 32 localise_enkf enkf_specific.f90, 48 mean pf_control::pf_control_type, 20 mixturerandomnumbers1d gen_rand.f90, 57 model_specific.f90, 35 mixturerandomnumbers2d gen_rand.f90, 57 model_specific.f90, 35 configure_model, 35 dist_st_ob, 36 h, 37 ht, 38 q, 39 qhalt, 40 r, 40 r, 40 r, 40 r, 40 r, 40 r, 41 solve_hqht_plus_r, 42 solve_r, 42 solve_rfalf, 43 mype_id comms, 11 myrank comms, 11 myrank romalrandomnumbers1d gen_rand.f90, 58 normalrandomnumbers2d gen_rand.f90, 58 normalrandomnumbers2d gen_rand.f90, 58 normalrandomnumbers2d gen_rand.f90, 59 npfs comms, 11 nproc comms, 11 nproc comms, 11 nproc comms, 11 nudgefac	<del>-</del>	hqht_plus_r, 13
tests.f90,71 histogram_data, 11 kill_histogram_data, 12 load_histogram_data, 12 rank_hist_list, 12 rank_hist_mums, 12 rhl_n, 12 rhl_n, 12 rhl_n, 12 rhl_n, 13 hopht_factor, 13 kill_hophtr, 13 load_hqhtr, 13 hopht_factor hqht_plus_r, 13 hqht_factor hqht_plus_r, 14 ht, 38 human_readable pf_control:pf_control_type, 19 initialise_mpi comms, 10 innerhqht_plus_r_1 operator_wrappers.f90, 62 innerr_1 operator_wrappers.f90, 63 insertionsort_d quicksort.f90, 80  k operator_wrappers.f90, 63 keep pf_control:pf_control_type, 20 nfac pf_control:pf_control_type, 20 nfac pf_control:pf_control_type, 20 nfac pf_control:pf_control_type, 20 normalrandomnumbers2d gen_rand.f90, 58 normalrandomnumbers2d gen_rand.f90, 59 npfs comms, 11 nproc kill_hqhtr hqht_plus_r, 13 killq qdata, 23 normal, 11 nudgefac	_ ·	loadq
histogram_data, 11 kill_histogram_data, 12 load_histogram_data, 12 rank_hist_list, 12 rank_hist_list, 12 rank_hist_list, 12 rank_hist_nums, 12 rhl_n, 12 rhn_n, 12 hqht_plus_r, 13 hqhtr_factor, 13 kill_hqhtr, 13 load_hqhtr, 13 hqhtr_tests tests.f90, 72 ht model_specific.f90, 38 human_eadable pf_control::pf_control_type, 19 initialise_mpi comms, 10 innerrhqht_plus_r_1 operator_wrappers.f90, 63 insertionsort_d quicksort.f90, 80  k operator_wrappers.f90, 63 keep pf_control::pf_control_type, 20 kill_histogram_data, 12 kill_hqhtr hqht_plus_r, 13 killq qdata, 23  rdata, 32 localise_enkf enkf_specific.f90, 48  mean pf_control::pf_control_type, 20 mixturerandomnumbers1d gen_rand.f90, 55 mixturerandomnumbers2d gen_rand.f90, 57 model_specific.f90, 35 configure_model, 35 dist_st_ob, 36 h, 37 ht, 38 q, 39 qhalf, 40 r, 40 r, 40 r, 40 r, 41 solve_hqht_plus_r, 42 solve_r, 42 solve_r, 42 solve_r, 42 solve_r, 42 solve_r, 41 myrank comms, 11 myrank comms, 12 myra		qdata, 23
kill_histogram_data, 12 load_histogram_data, 12 rank_hist_list, 12 rank_hist_nums, 12 rhl_n, 12 rhl_n, 12 rhl_n, 12 rhl_n, 13 hqhtr_factor, 13 kill_hqhtr, 13 load_hqhtr, 13 hqhtr_lests tests.190, 72 ht model_specific.190, 38 human_readable pf_control:pf_control_type, 19 initialise_mpi comms, 10 innerhqht_plus_r_1 operator_wrappers.190, 63 keep pf_control:pf_control_type, 20 kill_histogram_data histogram_data qdata, 23  himan_read, 12 localise_enkf enkf_specific.190, 48  mean  pf_control::pf_control_type, 20 mixturerandomnumbers1d gen_rand.190, 55 mixturerandomnumbers2d gen_rand.190, 57 model_specific.190, 35 configure_model, 35 dist_st_ob, 36 h, 37 nodel_specific.190, 35 configure_model, 35 dist_st_ob, 36 h, 37 ht, 38 q, 39 qhalf, 40 r, 40 rhalf, 41 solve_hqht_plus_r, 42 solve_r, 42 solve_rhalf, 43 mype_id comms, 11 myrank comms, 12 myranh comms, 11 myrank comms, 12 myranh comms, 12 myranh comms, 10 myranh comms, 10	•	loadr
load_histogram_data, 12 rank_hist_list, 12 rank_hist_lust, 12 rank_hist_nums, 12 rhl_n, 12 rhl_n, 12 rhl_n, 12 rhl_n, 13 hqhtr_factor, 13 hqhtr_factor hqht_plus_r, 13 load_hqhtr, 13 hqhtr_factor hqht_plus_r, 13 hqhtr_tests tests.f90, 72 ht model_specific.f90, 38 human_readable pf_control:pf_control_type, 19 initialise_mpi comms, 10 innerhqht_plus_r_1 operator_wrappers.f90, 63 insertionsort_d quicksort.f90, 80  k operator_wrappers.f90, 63 keep pf_control:pf_control_type, 20 kill_histogram_data histogram_data, 12 kill_hqhtr hqht_plus_r, 13 killq qdata, 23  mean pf_control:pf_control_type, 20 mixturerandomnumbers1d gen_rand.f90, 55 mixturerandomnumbers2d gen_rand.f90, 59 normalrandomnumbers1d gen_rand.f90, 59 normalrandomnumbers2d gen_	· —	rdata, 32
load_histogram_data, 12	kill_histogram_data, 12	localise enkf
rank_hist_list, 12 rank_hist_nums, 12 rhl_n, 12 rhn_n, 12 hqht_plus_r, 13 hqhtr_factor, 13 kill_hqhtr, 13 load_hqhtr, 13 hqhtr_factor hqht_plus_r, 13 hqhtr_factor hqht_plus_r, 13 hqhtr_tests tests.f90, 72 ht model_specific.f90, 38 human_readable pf_control:pf_control_type, 19 initialise_mpi comms, 10 innerhqht_plus_r_1 operator_wrappers.f90, 63 insertionsort_d quicksort.f90, 80  k operator_wrappers.f90, 63 keep pf_control:pf_control_type, 20 kill_histogram_data histogram_data, 12 kill_hqhtr hqht_plus_r, 13 killq qdata, 23  mean pf_control:pf_control_type, 20 mixturerandomnumbers1d gen_rand.f90, 55 mixturerandomnumbers2d gen_rand.f90, 55 mixturerandomnumbers1d gen_rand.f90, 59 normalrandomnumbers1d gen_rand.f90, 59 normalrandomnumbers2d gen_rand.f90, 58 normalrandomnumbers2d gen_rand.f90, 59 normalrandomnumber	load_histogram_data, 12	<del>_</del>
rhl_n, 12 rhn_n, 12 hqht_plus_r, 13 hqhtr_factor, 13 kill_hqhtr, 13 load_hqhtr, 13 hqhtr_factor hqht_plus_r, 13 hqhtr_factor hqht_plus_r, 13 hqhtr_fests tests.f90, 72 ht model_specific.f90, 38 human_readable pf_control::pf_control_type, 19 initialise_mpi comms, 10 innerrhqht_plus_r_1 operator_wrappers.f90, 62 innerr_1 operator_wrappers.f90, 63 keep pf_control::pf_control_type, 20 kill_histogram_data histogram_data, 12 kill_pqhtr hqht_plus_r, 13 kill_pdata, 23 hqhtr_factor, 13 mixturerandomnumbers2d gen_rand.f90, 55 mixturerandomnumbers1d gen_rand.f90, 55 mixturerandomnumbers1d gen_rand.f90, 55 mixturerandomnumbers1d gen_rand.f90, 55 mixturerandomnumbers1d gen_rand.f90, 55 mixturerandomnumbers2d gen_rand.f90, 55 mixturerandomnumbers1d gen_rand.f90, 55 mixturerandomnumbers2d gen_rand.f90, 55 mixturerandomnumbers1d gen_rand.f90, 55 mixturerandomnumbers2d gen_rand.f90, 55 mixturerandomnumbers2d gen_rand.f90, 55 mixturerandomnumbers2d gen_rand.f90, 55 mixturerandomnumbers1d gen_rand.f90, 55 mixturerandomnumbers2d gen_rand.f90, 55 mixturerandomnumbers1d gen_rand.f90, 55 mixturerandomnumbers1d gen_rand.f90, 55 mixturerandomnumbers1d gen_rand.f90, 55 mixturerandomnumbers1d gen_rand.f90, 55 mixtu	rank_hist_list, 12	
rhl_n, 12 rhn_n, 12 hqht_plus_r, 13 hqhtr_factor, 13 kill_hqhtr, 13 load_hqhtr, 13 hqhtr_factor hqht_plus_r, 13 hqhtr_factor hqht_plus_r, 13 hqhtr_tests tests.f90, 72 ht model_specific.f90, 38 human_readable pf_control::pf_control_type, 19 initialise_mpi comms, 10 innerhqht_plus_r, 1 operator_wrappers.f90, 62 innerr_1 operator_wrappers.f90, 63 keep pf_control::pf_control_type, 20 kill_histogram_data histogram_data, 12 kill_hqhtr qdata, 23  pf_control::pf_control_type, 20 mixturerandomnumbers1d gen_rand.f90, 55 mixturerandomnumbers2d gen_rand.f90, 55 mixturerandomnumbers1d gen_rand.f90, 55 mixturerandomnumbers2d gen_rand.f90, 55 mixturerandomnumbers1d gen_rand.f90, 55 mixturerandomnumbers1d gen_rand.f90, 55 mixturerandomnumbers2d gen_rand.f90, 55 mixturerandomnumbers1d gen_rand.f90, 55 mixturerandomnumbers1d gen_rand.f90, 55 mixturerandemonumbers1d gen_rand.f90, 55 mixturerandomnumbers1d gen_rand.f90, 55 mixturerandemonumbers1d gen_rand.f90, 55 mixt	rank_hist_nums, 12	mean
rhn_n, 12 hqht_plus_r, 13 hqhtr_factor, 13 kill_hqhtr, 13 load_hqhtr, 13 hqhtr_factor hqht_plus_r, 13 hqhtr_factor hqtp_plus_r, 14 hqtp_plus_r, 14 hqht_plus_r, 13 hqhtr_plus_r, 14 hqht_plus_r, 13 hqhtr_plus_r, 14	rhl_n, 12	
hqht_plus_r, 13         gen_rand.f90, 55           hqhtr_factor, 13         gen_rand.f90, 55           hqht_plus_r, 13         gen_rand.f90, 57           hqht_plus_r, 13         gen_rand.f90, 57           hqht_plus_r, 13         gen_rand.f90, 55           mixturerandomnumbers2d         gen_rand.f90, 55           mixturerandomnumbers2d         gen_rand.f90, 55           mixturerandomnumbers2d         gen_rand.f90, 55           mixturerandomnumbers2d         dist_st_oble.file           h, 37         ht, 38           t, 40         rhalf, 40           r, 40         rhalf, 41           solve_nalf, 40         r, 40           rhalf, 41         solve_nalf, 43           mype_id         comms, 11           operator_wrappers.f90, 62         mens           pf_control::pf_control_type, 20           k         pf_control::pf_control_type, 20           risc         pf_control::pf_	rhn_n, 12	
hqhtr_lactor, 13 kill_hqhtr, 13 load_hqhtr, 13 hqhtr_factor hqht_plus_r, 13 hqhtr_tests tests.f90, 72 ht model_specific.f90, 38 human_readable pf_control::pf_control_type, 19 initialise_mpi comms, 10 innerhqht_plus_r_1 operator_wrappers.f90, 62 innerr_1 operator_wrappers.f90, 63 keep pf_control::pf_control_type, 20 kill_histogram_data histogram_data, 12 kill_hqhtr hqht_plus_r, 13 killq qdata, 23  mixturerandomnumbers2d gen_rand.f90, 57 model_specific.f90, 35 configure_model, 35 dist_st_ob, 36 h, 37 ht, 38 q, 39 qhalf, 40 r, 40 rhalf, 41 solve_hqht_plus_r, 42 solve_rhalf, 43 mype_id comms, 10 comms, 11 myrank comms, 11 myrank comms, 11 myrank comms, 11 operator_wrappers.f90, 63 normalrandomnumbers1d gen_rand.f90, 58 normalrandomnumbers2d gen_rand.f90, 59 npfs comms, 11 nproc comms, 11 nproc comms, 11 nproc comms, 11 npoc comms, 11 nproc comms, 11	hqht_plus_r, 13	
kill_nqhtr, 13 load_nqhtr, 13 hqhtr_factor hqht_plus_r, 13 hqhtr_tests tests.f90, 72 ht model_specific.f90, 38 human_readable pf_control::pf_control_type, 19 initialise_mpi comms, 10 innerhqht_plus_r_1 operator_wrappers.f90, 62 innerr_1 operator_wrappers.f90, 63 insertionsort_d quicksort.f90, 80  k operator_wrappers.f90, 63 keep pf_control::pf_control_type, 20 kill_histogram_data histogram_data, 12 killq hqdata, 23  killq qdata, 23  gen_rand.f90, 57 model_specific.f90, 35 configure_model, 35 dist_ste_ob, 36 h, 37 ht, 38 q, 39 qhalf, 40 r, 40 rhalf, 41 solve_hqht_plus_r, 42 solve_r, 42 solve_r, 42 solve_rhalf, 43 mype_id comms, 11 myrank comms, 11 myrank comms, 11 myrank readable pf_control::pf_control_type, 20 nfac k pf_control::pf_control_type, 20 normalrandomnumbers1d gen_rand.f90, 58 normalrandomnumbers2d gen_rand.f90, 59 npfs comms, 11 nproc comms, 11 nudgefac	hqhtr_factor, 13	
hqht_factor hqht_plus_r, 13 hqhtr_fests tests.f90, 72 ht model_specific.f90, 38 human_readable pf_control::pf_control_type, 19 initialise_mpi comms, 10 innerhqht_plus_r_1 operator_wrappers.f90, 62 innerr_1 operator_wrappers.f90, 63 insertionsort_d quicksort.f90, 80  k operator_wrappers.f90, 63 keep pf_control::pf_control_type, 20 kill_histogram_data histogram_data histogram_data histogram_data histogram_data histogram_data hittp_dis_r, 13 killq qdata, 23  model_specific.f90, 35 configure_model, 25 configure_model, 25 configure_model, 25 configure_model, 25 configure_model, 25 configure_nodel, 25 configure_confol. p, 37 configure_nodel, 25 configure_nodel, 25 configure_confol. p, 37 configure_confol. p, 39 colleger pf_control:pf_control.pde pf_control:pf_control.pde pf_control:pf_control.pde pf_control:pf_control.pde pd_nade_solve_fate pf_control:pf_control.pde pf_control:pf_control.pde pd_nade_solve_fate pf_control:pf_control.pde pd_nade_solve_fate pf_control:pf_control.pde pd_nade_solve_fate pf_control:pf_control.pde pd_nade_solve_fate pf_control:pf_control.pde pd_nade_solve_fate pf_control:pf_control.pde pd_nade_solve_fate pf_control:pf_control.pde pd_nade_solve_fat	kill_hqhtr, 13	
nqht_plus_r, 13 hqht_plus_r, 13 hqht_tests tests.f90, 72 ht model_specific.f90, 38 human_readable pf_control::pf_control_type, 19 initialise_mpi comms, 10 innerhqht_plus_r, 1 operator_wrappers.f90, 62 innerr_1 operator_wrappers.f90, 63 insertionsort_d quicksort.f90, 80  k operator_wrappers.f90, 63 keep pf_control::pf_control_type, 20 kill_histogram_data histogram_data histogram_data, 12 killq hqdata, 23  killq qdata, 23  int, 37 ht, 38 dist_st_ob, 36 h, 37 ht, 38 human_readable r, 40 r, 40 rhalf, 41 solve_hqht_plus_r, 42 solve_r, 42 solve_r, 42 solve_r, 42 solve_r, 42 solve_rhalf, 43 mype_id comms, 11 myrank comms, 11 myrank romms, 11 nproc romms, 11 nproc romms, 11 nudgefac	_ ·	_
hqht_plus_r, 13 hqht_tests tests.f90, 72 ht model_specific.f90, 38 human_readable pf_control::pf_control_type, 19 initi init comms, 10 innerhqht_plus_r_1 operator_wrappers.f90, 62 innerr_1 operator_wrappers.f90, 63 insertionsort_d quicksort.f90, 80  k operator_wrappers.f90, 63 keep pf_control::pf_control_type, 20 kill_histogram_data histogram_data histogram_data hittogram_data hittogram_data hittogram_data hittogram_data hittogram_data qdata, 23  killq qdata, 23  dist_st_ob, 36 dist_st_ob, 36 dist_st_ob, 36 dist_st_ob, 36 histogram_data cdist_st_ob, 36 histogram_data cdist_st_ob, 36 histogram_data cdist_st_ob, 36 hitt, 38 dist_st_ob, 36 hitt, 38 ht, 37 ht, 38 q, 39 qhalf, 40 r, 40 rhalf, 41 solve_hqht_plus_r, 42 solve_r, 42 solv	hghtr factor	— ·
hqhtr_tests tests.f90, 72 ht model_specific.f90, 38 human_readable pf_control::pf_control_type, 19 init pf_control::pf_control_type, 19 initialise_mpi comms, 10 innerhqht_plus_r_1 operator_wrappers.f90, 62 innerr_1 operator_wrappers.f90, 63 insertionsort_d quicksort.f90, 80  k operator_wrappers.f90, 63 keep pf_control::pf_control_type, 20 kill_histogram_data, 12 kill_qhtr hqht_plus_r, 13 killq qdata, 23  ht, 38 ht, 38 ht, 38 q, 39 qhalf, 40 r, 40 rhalf, 41 solve_hqht_plus_r, 42 solve_r, 42 solve_r, 42 solve_r, 42 solve_rhalf, 43 mype_id comms, 11 myrank romms, 11 operator_wrappers.f90, 63 pf_control::pf_control_type, 20 normalrandomnumbers1d gen_rand.f90, 58 normalrandomnumbers2d gen_rand.f90, 59 npfs comms, 11 nproc comms, 11 nproc comms, 11 nudgefac	• —	
tests.f90, 72  ht model_specific.f90, 38 human_readable pf_control::pf_control_type, 19 init pf_control::pf_control_type, 19 initialise_mpi comms, 10 innerhqht_plus_r_1 operator_wrappers.f90, 62 insertionsort_d quicksort.f90, 80  k pf_control::pf_control_type, 20 kill_histogram_data, 12 killq qdata, 23  ht, 38 ht, 38 q, 39 qhalf, 40 r, 40 rhalf, 41 solve_hqht_plus_r, 42 solve_r, 42 solve_route solve_route rhalf, 43 mype_id comms, 11 myrank comms, 15 myrank comms, 11 myrank comms, 15 myrank comms, 11 myrank comms, 11 myrank comms, 11 nproc	. — —	:
ht model_specific.f90, 38	•	
model_specific.f90, 38 human_readable pf_control::pf_control_type, 19 init  init pf_control::pf_control_type, 19 initialise_mpi comms, 10 innerhqht_plus_r_1 operator_wrappers.f90, 62 innerr_1 operator_wrappers.f90, 63 insertionsort_d quicksort.f90, 80  k operator_wrappers.f90, 63 keep pf_control::pf_control_type, 20 kill_histogram_data histogram_data, 12 killq qdata, 23  mq, 39 qhalf, 40 r, 40 rhalf, 41 solve_hqht_plus_r, 42 solve_r, 42 solve_rhalf, 43 mype_id comms, 11 myrank comms, 11 myrank comms, 11 mproc pf_control::pf_control_type, 20 nfac pf_control::pf_control_type, 20 normalrandomnumbers1d gen_rand.f90, 58 normalrandomnumbers2d gen_rand.f90, 59 norms, 11 nproc comms, 11 nproc comms, 11 nproc comms, 11 nudgefac		
human_readable pf_control::pf_control_type, 19  init  init     pf_control::pf_control_type, 19  initialise_mpi     comms, 10  innerhqht_plus_r_1     operator_wrappers.f90, 62  innerr_1     operator_wrappers.f90, 63  insertionsort_d     quicksort.f90, 80  k     operator_wrappers.f90, 63  keep     pf_control::pf_control_type, 20  kill_histogram_data     histogram_data, 12  killq     qdata, 23  human_readable     r, 40     rhalf, 41     solve_hqht_plus_r, 42     solve_r, 42     solve_rhalf, 43     mype_id     comms, 11     myrank     comms, 11     myrank     comms, 11      operator_wrappers.f90, 63     norms     pf_control::pf_control_type, 20     normalrandomnumbers1d     gen_rand.f90, 58     normalrandomnumbers2d     gen_rand.f90, 59     npfs     comms, 11     nproc     comms, 11     nproc     comms, 11     nproc     comms, 11     nudgefac		•
pf_control::pf_control_type, 19  init  pf_control::pf_control_type, 19  initialise_mpi     comms, 10  innerhqht_plus_r_1     operator_wrappers.f90, 62  innerr_1     operator_wrappers.f90, 63  insertionsort_d     quicksort.f90, 80  k     operator_wrappers.f90, 63  keep     pf_control::pf_control_type, 20  keep     pf_control::pf_control_type, 20  kill_histogram_data     histogram_data, 12  killq     qdata, 23  r, 40  rhalf, 41  solve_hqht_plus_r, 42  solve_r, 42  solve_r, 42  solve_rhalf, 43  mype_id  comms, 11  myrank  comms, 11  myrank  r, 40  rhalf, 41  solve_hqht_plus_r, 42  solve_r, 42  solve_rhalf, 43  myrank  comms, 11  myrank  rnens  pf_control::pf_control_type, 20  normal pf_control::pf_control_type, 20  normalrandomnumbers1d  gen_rand.f90, 58  normalrandomnumbers2d  gen_rand.f90, 59  npfs  killq     comms, 11  nproc     comms, 11  nproc     comms, 11  nudgefac	— ·	•
init  pf_control::pf_control_type, 19 initialise_mpi comms, 10 innerhqht_plus_r_1 operator_wrappers.f90, 62 insertionsort_d quicksort.f90, 80  k operator_wrappers.f90, 63 keep pf_control::pf_control_type, 20 kill_histogram_data histogram_data, 12 killq qdata, 23  initialise_mpi solve_hqht_plus_r, 42 solve_r, 42 solve_role so	_	
pf_control::pf_control_type, 19 initialise_mpi	p	rhalf, 41
pf_control::pf_control_type, 19 initialise_mpi	init	solve_hqht_plus_r, 42
initialise_mpi comms, 10 innerhqht_plus_r_1 operator_wrappers.f90, 62 innerr_1 operator_wrappers.f90, 63 insertionsort_d quicksort.f90, 80  k operator_wrappers.f90, 63 keep pf_control::pf_control_type, 20 kill_histogram_data histogram_data, 12 killq qdata, 23  innerhqht_plus_r_, 13 mype_id comms, 11 myrank comms, 11 myrank comms, 11 myrank nens pf_control::pf_control_type, 20 nens pf_control::pf_control_type, 20 nens pf_control::pf_control_type, 20 normalrandomnumbers1d gen_rand.f90, 58 normalrandomnumbers2d gen_rand.f90, 59 npfs comms, 11 nproc comms, 11		solve_r, 42
comms, 10 innerhqht_plus_r_1     operator_wrappers.f90, 62 innerr_1     operator_wrappers.f90, 63 insertionsort_d     quicksort.f90, 80  k     operator_wrappers.f90, 63 keep     pf_control::pf_control_type, 20     normalrandomnumbers1d     keep     pf_control::pf_control_type, 20     kill_histogram_data     histogram_data, 12     kill_hqhtr     hqht_plus_r, 13 killq     quadata, 23  mype_id     comms, 11 myrank     comms, 11 moralrandom:     pf_control::pf_control_type, 20     normalrandomnumbers1d     gen_rand.f90, 58     normalrandomnumbers2d     gen_rand.f90, 59     norms, 11     nproc     comms, 11     nproc     comms, 11     nudgefac		solve_rhalf, 43
innerhqht_plus_r_1 operator_wrappers.f90, 62 innerr_1 operator_wrappers.f90, 63 insertionsort_d quicksort.f90, 80  k operator_wrappers.f90, 63 keep operator_wrappers.f90, 63 keep pf_control::pf_control_type, 20 normalrandomnumbers1d gen_rand.f90, 58 normalrandomnumbers2d kill_histogram_data histogram_data, 12 kill_hqhtr omalrandomnumbers comms, 11 nproc killq odata, 23 comms, 11 nproc	_ ·	mype_id
operator_wrappers.f90, 62 innerr_1 operator_wrappers.f90, 63 insertionsort_d quicksort.f90, 80  k operator_wrappers.f90, 63 keep operator_wrappers.f90, 63 keep pf_control::pf_control_type, 20 kill_histogram_data histogram_data, 12 kill_hqhtr hqht_plus_r, 13 killq qdata, 23  myrank comms, 11 nens pf_control::pf_control_type, 20 nfac pf_control::pf_control_type, 20 normalrandomnumbers1d gen_rand.f90, 58 normalrandomnumbers2d gen_rand.f90, 59 npfs comms, 11 nproc comms, 11 nproc comms, 11 nudgefac	•	comms, 11
innerr_1 operator_wrappers.f90, 63 insertionsort_d quicksort.f90, 80  k operator_wrappers.f90, 63 keep operator_wrappers.f90, 63 keep pf_control::pf_control_type, 20 normalrandomnumbers1d gen_rand.f90, 58 normalrandomnumbers2d kill_histogram_data histogram_data, 12 kill_hqhtr hqht_plus_r, 13 killq qdata, 23 comms, 11 nens pf_control::pf_control_type, 20 normalrandomnumbers1d gen_rand.f90, 59 npfs comms, 11 nproc comms, 11 nproc comms, 11		myrank
operator_wrappers.f90, 63 insertionsort_d     quicksort.f90, 80  k		comms, 11
insertionsort_d quicksort.f90, 80  k operator_wrappers.f90, 63 keep pf_control::pf_control_type, 20 normalrandomnumbers1d gen_rand.f90, 58 pf_control::pf_control_type, 20 kill_histogram_data histogram_data, 12 kill_hqhtr hqht_plus_r, 13 killq qdata, 23  nens pf_control::pf_control_type, 20 normalrandomnumbers1d gen_rand.f90, 58 normalrandomnumbers2d gen_rand.f90, 59 npfs comms, 11 nproc comms, 11 nudgefac	<del>-</del>	
quicksort.f90, 80  k  operator_wrappers.f90, 63  keep  pf_control::pf_control_type, 20  normalrandomnumbers1d  gen_rand.f90, 58  pf_control::pf_control_type, 20  kill_histogram_data  histogram_data, 12  kill_hqhtr  hqht_plus_r, 13  killq  qdata, 23  pf_control::pf_control_type, 20  normalrandomnumbers2d  gen_rand.f90, 59  norms, 11  nproc  comms, 11  nproc		nens
k pf_control::pf_control_type, 20 operator_wrappers.f90, 63 normalrandomnumbers1d keep gen_rand.f90, 58 pf_control::pf_control_type, 20 normalrandomnumbers2d kill_histogram_data gen_rand.f90, 59 histogram_data, 12 npfs kill_hqhtr comms, 11 hqht_plus_r, 13 nproc killq comms, 11 qdata, 23 nudgefac		pf control::pf control type, 20
operator_wrappers.f90, 63 keep	quioksort.100, 00	
operator_wrappers.f90, 63 keep	k	pf control::pf control type, 20
keep gen_rand.f90, 58 pf_control::pf_control_type, 20 normalrandomnumbers2d kill_histogram_data gen_rand.f90, 59 histogram_data, 12 npfs kill_hqhtr comms, 11 hqht_plus_r, 13 nproc killq comms, 11 qdata, 23 nudgefac		
pf_control::pf_control_type, 20 kill_histogram_data	. –	
kill_histogram_data gen_rand.f90, 59 histogram_data, 12 npfs kill_hqhtr comms, 11 hqht_plus_r, 13 nproc killq comms, 11 qdata, 23 nudgefac	•	_
histogram_data, 12  kill_hqhtr comms, 11 hqht_plus_r, 13  killq comms, 11 qdata, 23  npfs  comms, 11 nproc comms, 11 nudgefac		
kill_hqhtr       comms, 11         hqht_plus_r, 13       nproc         killq       comms, 11         qdata, 23       nudgefac		
hqht_plus_r, 13 nproc killq comms, 11 qdata, 23 nudgefac	_	•
killq comms, 11 qdata, 23 nudgefac		·
qdata, 23 nudgefac		•
•	•	
pi_controlpi_control_type, 20	•	_
	MIII	pi_controlpi_control_type, 20

sizes, 33 operator_wrappers.190 bprime, 61 innerhight_plus_r_1, 62 innerhight_	aha dim	nf couple f00
operator_wrappers.f90 bprime, 61 innertrght_plus_r_1, 62 innerr_1, 63 k, 63 output_from_pf data_io.190, 77  parse_pf_parameters pf_control. 15 particles pf_control.particle (.90) perturb_particle, 64 update_state, 65 pf pf_control, 17 pf_control, 17 pf_control, 17 pf_control, 18 parse_pf_parameters, 15 pf, 17 set_pf_control, 19 couple_root, 19 efac, 19 gen_data, 19 gen_data, 19 gen_data, 19 gen_data, 19 gen_data, 19 gen_data, 20 nens, 20 ners, 20 particles, 20 particles, 20 particles, 20 particles, 21 time_bwn_obs_ 22 use_maen, 22 use_mean, 22 use_weak, 22 use_mean, 22 use_weak, 22 use_mean, 22 use_weak, 22 use_mean, 22 use_weak, 22 use_man, 22 use_weak, 22 use_man, 22 use_weak, 22 use_man, 22 use_man, 22 use_man, 22 use_weak, 22 use_man, 23 under.fr proposal_filter.f20 proposal_filter.f90 proposal_filter.f90 p	obs_dim	pf_couple.f90
bprime, 61 innerhqht_plus_r_1, 62 inner_1, 63 k, 63 comms, 11 proposal_filter.f90, 52 proposal_filter.f90, 52 proposal_filter.f90, 52 proposal_filter.f90, 52 proposal_filter.f90 proposal_filter.f90, 52 proposal_filter.f90, 52 proposal_filter.f90 proposal_filter.f90 proposal_filter.f90 proposal_filter.f90 proposal_filter.f90 proposal_filter.f90, 52 proposal_filter.f90 proposal_filter.	•	•
innerhant_plus_r_1, 62 innerhant_plus_r_1, 62 innerhant_plus_r_1, 62 innerhant_plus_r_1, 62 innerhant_plus_r_1, 62 innerhant_plus_r_1, 63 k, 63  output_from_pl data_io.f90, 77  parse_pf_parameters pf_control, 15  particles pf_control.tpf_control_type, 20 perturb_particle 190, 64 perturb_particle 64 update_state, 65 pf pf_control, 17 pf_control, 17 pf_control, 14 allocate_pf, 15 deallocate_pf, 15 deallocate_pf, 15 parse_pf_parameters, 15 pf, 17 count, 19 couple_root, 19 efac, 19 gen_data, 19 gen_data, 19 gen_data, 19 gen_data, 19 gen_data, 20 nens, 20 particles, 21 time_bwn_obs, 21 time_bwn_obs, 21 time_bwn_obs, 21 time_bwn_obs, 21 time_bwn_obs, 21 time_bwn_obs, 21 time_bwn_exe use_mean, 22 use_weak, 22 use_weak, 22 use_mean, 22 use_m		
innerr_1, 63     k, 63  output_from_pf     data_io.f90, 77  parse_pf_parameters     pf_control, 15     particles     pf_control:pf_control_type, 20     perturb_particle.f90, 64     perturb_particle, 64     update_state, 65     pf_control, 17     pf_control, 14     allocate_pf, 15     parse_pf_parameters, 15     pf, 17     set_pf_control, 18     pf_control, 19     set_pf_control, 19     set_pf_control, 19     set_pf_control, 19     set_pf_control, 19     set_pf_control, 19     set_pf_control, 16     pf_control;pf_control_type, 17     count, 19     set_pf_control, 16     pf_control:pf_control_type, 17     count, 19     set_pf_control, 16     pf_control:pf_control_type, 17     count, 19     set_pf_control, 19     set_pf_control_type, 17     count, 19     set_pf_control_type, 17     set_pf_control_type, 17	•	,
k, 63		•
output_from_pf		•
data_io.f90, 77  parse_pf_parameters pf_control, 15 particles pf_control:pf_control_type, 20 perturb_particle perturb_particle, 64 update_state, 65 pf _control, 17 pf_control, 14 allocate_pf, 15 deallocate_pf, 15 deallocate_pf, 15 pf_control_type, 17 count, 19 count, 19 count, 19 gen_data, 19 gen_data, 19 gen_data, 20 nens, 20 psi, 20 qscale, 21 time_bwn_obs, 21 time_obs, 22 use_mean, 22 use_mean, 22 use_mean, 22 use_traj, 22 use_weak, 22 lingamma, 26 lilter, 52 psi proposal_filter, 52 psi pf_control:pf_control_type, 20 qdata, 24 qdata, 23 licate, 39 qdata, 23 licate, 4 qdata, 23 licate, 23 qdata, 23 qdata, 24 qdata, 24 qdata, 24 qdata, 24 qdata, 24 qrow qdata,	•	• • —
parse_pf_parameters     pf_control, 15     particles     pf_control::pf_control_type, 20     perturb_particle.90, 64     perturb_particle.90     perturb_particle.64     update_state, 65     pf_control, 17     pf_control, 19     count, 19     pen_data, 19     pen_data, 19     pen_data, 19     pen_data, 19     pen_data, 19     pen_data, 20     pen_q, 20     pen_s, 20     pen_s, 20     particles, 20     particle, 20     particle		
parse_pf_parameters     pf_control, 15     particles     pf_control::pf_control_type, 20     perturb_particle.f90, 64     perturb_particle, 64     update_state, 65     pf_control, 17     pf_control, 14     allocate_pf, 15     parse_pf_parameters, 15     pf, 17     set_pf_controls, 16     pf_control::pf_control_type, 17     count, 19     couple_root, 19     gen_data, 19     gen_data, 20     nens, 20     nens, 20     nens, 20     nens, 20     nens, 20     nens, 20     particles, 20     particles, 20     particle, 64     pf_control, 17     set_pf_control, 16     pf_control, 17     set_pf_control, 16     pf_control, 17     set_pf_control, 16     pf_control, 19     couple_root, 19     qedata, 24     qrow, 24     qro		
pf_control, 15 particles pr_control::pf_control_type, 20 perturb_particle perturb_particle.f90, 64 perturb_particle.f90 perturb_particle.f90 perturb_particle, 64 update_state, 65 pf pf_control, 17 pf_control, 17 pf_control, 17 allocate_pf, 15 deallocate_pf, 15 pf. 17 set_pf_control_type, 17 count, 19 efac, 19 gen_data, 19 gen_data, 19 gen_data, 19 human_readable, 19 init, 19 keep, 20 len, 20 mean, 20 mean, 20 mean, 20 mean, 20 mean, 20 particles, 20 particles, 20 particles, 20 particles, 20 particles, 21 time_bwn_obs, 21 time_bwn_obs, 21 time_bsc, 21 type, 21 use_traj, 22 use_traj, 24 udata, 24 udata, 24 udata, 24 udata,	parse_pf_parameters	
particles     pf_control::pf_control_type, 20     perturb_particle     perturb_particle.90, 64     perturb_particle.64     update_state, 65     pf_control, 17     pf_control, 14     allocate_pf, 15     parse_pf_parameters, 15     pf, 17     set_pf_control_type, 17     count, 19     couple_root, 19     gen_data, 19     gen_data, 19     gen_data, 20     nens, 20     nens, 20     nens, 20     nens, 20     nens, 20     nens, 20     particles, 20     particles, 90     perturb_particle, 64     update_state, 65     pf_control, 17     datla, 24     data, 23     killq, 23     loadq, 23     qcol, 24     data, 23     qcol, 24     qdata, 23     qcol, 24     qdata, 23     qcol, 24     qdata, 24     qne, 24     qre, 24     qre, 24     qre, 24     qval, 24     qval, 24     qval, 24     qval, 24     qdata, 24     qrow     qdata, 29     qdata, 29     qdata, 29     qdata, 29     qdata, 29	pf_control, 15	•
perturb_particle     perturb_particle.190, 64     perturb_particle.190     perturb_particle.64     update_state, 65  pf  pf_control, 17  pf_control, 14     allocate_pf, 15     parse_pf_parameters, 15     pf, 17     set_pf_control:pf_control type, 17     count, 19     count, 19     gen_data, 19     gen_data, 19     gen_data, 20     near, 20     particle.90     perturb_particle, 64     quotata, 24     qdata, 24     quotata, 24     quotat	particles	1 = 1 = -71 /
perturb_particle.190, 64 perturb_particle.64     update_state, 65 pf     perturb_particle.64     update_state, 65 pf     pf_control, 17 pf_control, 14     allocate_pf, 15     deallocate_pf, 15     parse_pf_parameters, 15     pf, 17     set_pf_controls, 16 pf_control:pf_controls, 16 pf_control:pf_control, 19     couple_root, 19     efac, 19     gen_data, 19     gen_data, 19     gen_data, 19     gen_data, 20     len, 20     nean, 20     retace, 21     tho, 21     talagrand, 21     time_bwn_obs, 21     time_bwn_obs, 21     time_bs, 21     time_bs, 21     time_step, 22     use_mean, 22     use_mean, 22     use_traj, 22     use_traj, 22     use_traj, 22     use_weak, 22     use_weak, 22     use_weak, 22     use_weak, 22     use_mean, 26     updata, 24     qetests     tests.190, 73     qeol     tests.190, 73     qeol     qetata, 24     qdata, 23     killq, 23     loadq, 23     qidaq, 23     qidaq, 24     qdag, 24     qrow, 24     qro		q
perturb_particle.f90     perturb_particle, 64     update_state, 65  pf     pf     pf_control, 17     pf_control, 14     allocate_pf, 15     deallocate_pf, 15     parse_pf_parameters, 15     pf, 17     set_pf_controls, 16     pf_control;pf_control_type, 17     count, 19     couple_root, 19     efac, 19     gen_data, 19     gen_data, 19     gen_data, 19     gen_data, 19     init, 19     keep, 20     len, 20     mean, 20     nens, 20     nafac, 20     nafac, 20     particles, 20     particles, 20     particles, 20     particles, 20     particle, 21     time_bwn_obs, 21     time_bs, 21     time_bs, 21     time_step, 22     use_mean, 22     use_mean, 22     use_mean, 22     use_traj, 22     use_traj, 22     use_traj, 22     use_weak, 22     use_weak, 22     use_weak, 22     use_weak, 22     use_mean, 26     data, 24     qdata, 24     qdata, 24     qrow     qdata, 24		model_specific.f90, 39
perturb_particle, 64     update_state, 65  pf     pf     pf_control, 17  pf_control, 14     allocate_pf, 15     parse_pf_parameters, 15     pf, 17     set_pf_controls; 16     pf_control; 19     count, 19     count, 19     count, 19     gen_data, 19     gen_data, 19     gen_q, 19     human_readable, 19     init, 19     keep, 20     len, 20     mean, 20     nens, 20     nens, 20     nudgefac, 20     particles, 20     particles, 20     particles, 20     pascale, 21     time_bbx, 21     time_bbx, 21     time_bbx, 21     time_bbx, 21     timestep, 21     type, 21     use_mean, 22     use_mean, 22     use_lagrand, 22     use_lagrand, 22     use_lagrand, 22     use_lewak, 22     use_weak, 22     use_weak, 22     use_weak, 22     use_weak, 22     use_weak, 22     use_lagrand, 26     kiliq, 23     qdata, 23     qdata, 23     qdata, 24     qrow, 24    qrow, 24     qrow, 24     qrow, 24     qrow, 24     qrow, 24    qrow, 24     qrow, 24     qrow, 24     qrow, 24     qrow, 24    qrow, 24     qrow, 24     qrow, 24     qrow, 24     qrow, 24    qrow, 24     qrow, 24     qrow, 24     qrow, 24     qrow, 24     qrow, 24     qrow, 24     qrow, 24     qrow, 24     qrow, 24		q_tests
update_state, 65  pf		tests.f90, 73
pf pf_control, 17 pf_control, 14 allocate_pf, 15 parse_pf_parameters, 15 pf, 17 set_pf_controls, 16 pf_control:pf_control_type, 17 count, 19 couple_root, 19 gen_data, 19 gen_data, 19 gen_data, 19 gen_data, 19 init, 19 keep, 20 len, 20 nean, 20 nean, 20 nean, 20 nean, 20 nean, 20 particles, 20 particles, 20 particles, 20 particles, 20 qscale, 21 rho, 21 talagrand, 21 time_bwn_obs, 21 time_bwn_obs, 21 time_bwn_obs, 21 time_bs, 21 timestep, 21 type, 21 ufac, 22 use_mean, 22 use_mean, 22 use_mrae, 22 use_mrae, 22 use_wark, 22 use_weak, 22 use_meam, 26  killq, 23 loadd, 24 qrow, 24 qscale, 24 qval, 24 qdata, 24 qrow qdata, 24 qrow qdata, 24 quicksort.f90 insertionsort_d, 80 quicksort_d, 80 quicksort_d quicksort_f90, 80 qval qdata, 24 trandom, 25 bin_prob, 26 dp, 31 lngamma, 26		qcol
pf_control, 17 pf_control, 14 allocate_pf, 15 deallocate_pf, 15 deallocate_pf, 15 parse_pf_parameters, 15 pf, 17 set_pf_control:pf_control, 16 pf_control:pf_control_type, 17 couple_root, 19 efac, 19 gen_data, 19 gen_data, 19 gen_data, 19 gen_data, 20 len, 20 len, 20 nens, 20 nens, 20 nudgefac, 20 particles, 20 particles, 20 particles, 20 particles, 20 particles, 20 time_ptile time_bwn_obs, 21 time_obs, 21 time_obs, 21 time_step, 21 type, 21 ufac, 22 use_mean, 22 use_mean, 22 use_tral, 22 use_tral, 22 use_tral, 22 use_war, 22 use	• –	qdata, 24
pf_control, 14         allocate_pf, 15         qcol, 24           deallocate_pf, 15         qcol, 24           parse_pf_parameters, 15         qn, 24           pf, 17         qne, 24           set_pf_controls, 16         qrow, 24           pf_control:pf_control_type, 17         qscale, 24           count, 19         qdiag           efac, 19         qdata, 24           gen_data, 19         qhalf           gen_q, 19         model_specific.f90, 40           human_readable, 19         qn           init, 19         qdata, 24           keep, 20         qn           len, 20         qdata, 24           mean, 20         qrow           ners, 20         qdata, 24           nes, 20         qdata, 24           nes, 20         qdata, 24           nes, 20         qdata, 24           psi, 20         quicksort.f9control:pf_control:pf_control:pf_control:pf_control:pf_control:pf_control:pf_control:pf_control:pf_control:pf_control:pf_control:pf_control:pf_control.pf_contr	•	•
allocate_pf, 15     deallocate_pf, 15     deallocate_pf, 15     parse_pf_parameters, 15     pf, 17     set_pf_controls, 16     pf_control::pf_control_type, 17     count, 19     couple_root, 19     efac, 19     gen_data, 19     gen_data, 19     jen_q, 19     human_readable, 19     init, 19     keep, 20     len, 20     mean, 20     nens, 20     nafac, 20     nafac, 20     particles, 20     particles, 20     particles, 20     gexale, 21     time, 21     time, 21     time, 21     time, 22     use_mean, 22     use_mean, 22     use_mean, 22     use_trai, 22     use_trai, 22     use_weak, 22     use_weak, 22     use_weak, 22     use_weak, 22     use_weak, 22     use_mean, 26     qn, 24     qn, 24     qne, 24     qne, 24     qrow,	• —	•
deallocate_pf, 15     parse_pf_parameters, 15     pf, 17         set_pf_controls, 16     pf_control::pf_control_type, 17         count, 19         couple_root, 19         efac, 19         gen_data, 19         gen_q, 19         human_readable, 19         init, 19         keep, 20         len, 20         mean, 20         nens, 20         nade, 20         particles, 20         particles, 20         particles, 20         qscale, 21         time_bohs, 21         time_bohs, 21         time_bohs, 21         time_step, 21         type, 21         urded, 22         use_mean, 22         use_mean, 22         use_trai, 22         use_trai, 22         use_weak, 22         use_weak, 22         unidagn, 24         qn, 24         qn, 24         qne, 24         qrow, 24         qrolata, 24         qrow         qdata, 24         qrow         qrow         qdata, 24         qrow         qdata, 24         qrow         qrow         qdata, 24         qrow         qrow         qdata, 24	• —	
parse_pf_parameters, 15 pf, 17 set_pf_controls, 16 pf_control::pf_control_type, 17 count, 19 couple_root, 19 efac, 19 gen_data, 19 gen_q, 19 human_readable, 19 init, 19 keep, 20 len, 20 mean, 20 mean, 20 nens, 20 ndac, 20 ndac, 20 particles, 20 particles, 20 psi, 20 qscale, 21 rho, 21 talagrand, 21 time_bwn_obs, 21 time_bwn_obs, 21 time_bwn_obs, 21 time_bes, 21 type, 21 ufac, 22 use_mean, 22 use_mean, 22 use_twak, 22 use_weak, 22 use_weak, 22 use_weak, 22 use_weak, 22 use_weak, 22 use_weak, 22  nen, 24 qne, 24 qrow, 24 qdata, 24 qdiag qdata, 24 qdata, 24 qne qdata, 24 qrow qdata, 24 qrow qdata, 24 qscale pf_control::pf_control_type, 21 qdata, 24 quicksort_f90 insertionsort_d, 80 quicksort_d quicksort_d quicksort_f0, 80 qval		•
pf, 17 set_pf_controls, 16 pf_control:::pf_control_type, 17 count, 19 couple_root, 19 efac, 19 gen_data, 19 gen_q, 19 human_readable, 19 init, 19 keep, 20 len, 20 mean, 20 neas, 20 nudgefac, 20 particles, 20 particles, 20 particles, 20 qscale, 21 rho, 21 talagrand, 21 time_bwn_obs, 21 time_bwn_obs, 21 time_bwn_obs, 21 time_tota, 22 use_mean, 22 use_mean, 22 use_trai, 22 use_weak, 22  use_weak, 22  use_weak, 22  use_weak, 22  use_weak, 22  productive qrow qdata, 24 quicksort.f90 insertionsort_d, 80 quicksort_d quicksort_f90, 80 qval qtata, 24  r model_specific.f90, 40 r_tests tests.f90, 74 random, 25 bin_prob, 26 dp, 31 lngamma, 26	<del>-</del>	
set_pf_controls, 16 pf_control::pf_control_type, 17		•
pf_control::pf_control_type, 17		
count, 19     couple_root, 19     efac, 19     gen_data, 19     gen_q, 19     human_readable, 19     init, 19     keep, 20     len, 20     nens, 20     nens, 20     nudgefac, 20     particles, 20     particles, 20     qscale, 21     rho, 21     talagrand, 21     time_bwn_obs, 21     time_bwn_obs, 21     timestep, 21     type, 21     ufac, 22     use_mean, 22     use_mean, 22     use_traj, 22     use_var, 22     use_weak, 22      dyalata, 24     qdata, 24     qrow     qdata, 24     qrow     qdata, 24     qscale     pf_control::pf_control_type, 21     qdata, 24     quicksort.f90     insertionsort_d, 80     quicksort_d     quicksort_d     quicksort_d     rests     tests.f90, 74     random, 25     bin_prob, 26     dp, 31     lngamma, 26	<del>_</del> _	•
couple_root, 19 efac, 19 gen_data, 19 gen_q, 19 human_readable, 19 init, 19 keep, 20 len, 20 nean, 20 nean, 20 nudgefac, 20 particles, 20 qscale, 21 rho, 21 time_bwn_obs, 21 time_bwn_obs, 21 time_bwn_obs, 21 time_tobs, 21 type, 21 ufac, 22 use_mean, 22 use_mean, 22 use_traj, 22 use_waak, 22  use_waak, 22  use_waak, 22  use_waak, 22  qhalf model_specific.f90, 40 qn model_specific.f90, 40 qn qdata, 24 qrow qdata, 24 qrow qdata, 24 qscale pf_control::pf_control_type, 21 qdata, 24 quicksort_f90 insertionsort_d, 80 quicksort_d quicksort_d quicksort_f90, 80 qval  r model_specific.f90, 40 r_tests tests.f90, 74 random, 25 bin_prob, 26 dp, 31 lngamma, 26		•
efac, 19 gen_data, 19 gen_data, 19 gen_q, 19 human_readable, 19 init, 19 keep, 20 len, 20 mean, 20 nens, 20 nudgefac, 20 particles, 20 particles, 20 pascale, 21 rho, 21 talagrand, 21 time_bwn_obs, 21 time_bwn_obs, 21 time_bwn_obs, 21 time_step, 21 type, 21 ufac, 22 use_mran, 22 use_traj, 22 use_waak, 22  gen_data, 24 qhalf model_specific.f90, 40 qn qdata, 24 qrow qdata, 24 quicksort.f90 quicksort_f90, 80 qval qdata, 24 rests qdata, 24 qrow qore qore qdata, 24 qrow qore qore qore qdata, 24 qrow qore qore qore qore qore qore qore qore		•
gen_data, 19 gen_q, 19 human_readable, 19 init, 19 keep, 20 len, 20 nens, 20 nens, 20 nudgefac, 20 particles, 20 particles, 20 qscale, 21 rho, 21 talagrand, 21 time_bwn_obs, 21 time_bwn_obs, 21 time_bwn_obs, 21 time_sep, 21 type, 21 ufac, 22 use_mean, 22 use_mean, 22 use_traj, 22 use_waak, 22  gdata, 19 model_specific.f90, 40 qn qdata, 24 qrow qdata, 24 qrow qdata, 24 qscale pf_control::pf_control_type, 21 qdata, 24 quicksort.f90 insertionsort_d, 80 quicksort_d, 80 quicksort_d, 80 qval qdata, 24  r model_specific.f90, 40 r_tests tests.f90, 74 random, 25 bin_prob, 26 dp, 31 lngamma, 26	• —	
gen_q, 19 human_readable, 19 init, 19 keep, 20 len, 20 nens, 20 nens, 20 nudgefac, 20 particles, 20 qscale, 21 rho, 21 time, 21 time_bwn_obs, 21 time_bwn_obs, 21 time_texp, 21 type, 21 ufac, 22 use_mean, 22 use_traj, 22 use_weak, 22  model_specific.f90, 40 qn qdata, 24 qrow qdata, 24 quicksort.f90 quicksort_d, 80 quicksort_d, 80 quicksort_d, 80 qval qval qdata, 24 readata, 24 readom, 25 bin_prob, 26 dp, 31 lngamma, 26		•
human_readable, 19 init, 19 keep, 20 len, 20 mean, 20 nens, 20 ndgefac, 20 particles, 20 qscale, 21 rho, 21 talagrand, 21 time_obxn_obs, 21 time_bwn_obs, 21 time_bwn_obs, 21 type, 21 ufac, 22 use_mean, 22 use_traj, 22 use_weak, 22  mean, 20 qdata, 24 qrow qdata, 24 qrow qdata, 24 qscale pf_control::pf_control_type, 21 qdata, 24 quicksort.f90 insertionsort_d, 80 quicksort_d quicksort_d quicksort_d quicksort.f90, 80 qval qdata, 24  r model_specific.f90, 40 r_tests tests.f90, 74 random, 25 bin_prob, 26 dp, 31 lngamma, 26		•
init, 19 keep, 20 len, 20 mean, 20 mean, 20 nens, 20 nudgefac, 20 particles, 20 qscale, 21 rho, 21 time, 21 time_bwn_obs, 21 time_obs, 21 timestep, 21 type, 21 ufac, 22 use_mean, 22 use_traj, 22 use_weak, 22  lone qdata, 24 qrow qdata, 24 qscale pf_control::pf_control_type, 21 qdata, 24 quicksort.f90 insertionsort_d, 80 quicksort_d, 80 quicksort_d quicksort_d quicksort_f90, 80 qval quicksort.f90, 80 qval quicksort_f90, 80 qval qdata, 24 rho, 21 qdata, 24 rho, 21 quicksort_d quicksort_f90, 80 qval qdata, 24 random, 25 bin_prob, 26 dp, 31 lngamma, 26		<del>-</del> ·
keep, 20 len, 20 mean, 20 mean, 20 nens, 20 nudgefac, 20 particles, 20 qscale, 21 rho, 21 talagrand, 21 time_bwn_obs, 21 time_obs, 21 timestep, 21 type, 21		•
len, 20 mean, 20 nens, 20 nens, 20 nfac, 20 nudgefac, 20 particles, 20 qscale, 21 rho, 21 talagrand, 21 time_bwn_obs, 21 time_obs, 21 type, 21 ufac, 22 use_mean, 22 use_traj, 22 use_weak, 22  qdata, 24 qrow qdata, 24 qrow qdata, 24 qscale pf_control::pf_control_type, 21 qdata, 24 qscale pf_control::pf_control_type, 21 qdata, 24 quicksort.f90 qscale, 21 quicksort_d, 80 quicksort_d quicksort.f90, 80 qval qval qval qdata, 24 rnodel_specific.f90, 40 r_tests tests.f90, 74 random, 25 bin_prob, 26 dp, 31 lngamma, 26		·
mean, 20 nens, 20 nens, 20 nfac, 20 nudgefac, 20 particles, 20 qscale, 21 rho, 21 talagrand, 21 time_bwn_obs, 21 time_obs, 21 type, 21 ufac, 22 use_mean, 22 use_traj, 22 use_weak, 22  nrodgefac, 20 qdata, 24 qscale pf_control::pf_control_type, 21 qdata, 24 qscale pf_control::pf_control_type, 21 qdata, 24 quicksort.f90 quicksort_d, 80 quicksort_d quicksort_f0, 80 qval qval qdata, 24  r model_specific.f90, 40 r_tests tests.f90, 74 random, 25 bin_prob, 26 dp, 31 lngamma, 26		
nens, 20 nfac, 20 nudgefac, 20 particles, 20 psi, 20 qscale, 21 rho, 21 time, 21 time_obs, 21 timestep, 21 type, 21 ufac, 22 use_mean, 22 use_traj, 22 use_weak, 22  qdata, 24 qscale pf_control::pf_control_type, 21 qdata, 24 quicksort.f90 insertionsort_d, 80 quicksort_d a quicksort_d quicksort_foo, 80 qval qdata, 24  r qdata, 24 quicksort_d, 80 quicksort_d quicksort_foo, 80 qval qdata, 24  r r model_specific.f90, 40 r_tests tests.f90, 74 random, 25 bin_prob, 26 dp, 31 lngamma, 26		
nfac, 20 nudgefac, 20 particles, 20 psi, 20 qscale, 21 rho, 21 talagrand, 21 time, 21 time_bwn_obs, 21 timestep, 21 type, 21 ufac, 22 use_traj, 22 use_weak, 22  qscale pf_control::pf_control_type, 21 qdata, 24 quicksort.f90 insertionsort_d, 80 quicksort_d, 80 quicksort_d quicksort_f90, 80 quicksort_d quicksort.f90, 80 rudeta, 24 rests qscale pf_control::pf_control_type, 21 qdata, 24 restionsort_d, 80 quicksort_d quicksort_f90, 80 rudeta, 24 restionsort_d, 80 quicksort_d quicksort_f90, 80 rudeta, 24 restionsort_d, 80 rudeta, 24 restionsort_d, 80 quicksort_d quicksort_f90, 80 rudeta, 24 restionsort_d, 80 rudeta, 24 rudeta, 24 restionsort_d, 80 rudeta, 24 rude		•
nudgefac, 20 particles, 20 psi, 20 qscale, 21 rho, 21 talagrand, 21 time_bwn_obs, 21 type, 21 type, 21 type, 21 use_mean, 22 use_traj, 22 use_weak, 22  pf_control::pf_control_type, 21 qdata, 24 quicksort.f90 insertionsort_d, 80 quicksort_d quicksort_d quicksort.f90, 80 qval qval qval qdata, 24  r qdata, 24  r r r r r rests r rests, 90, 74 random, 25 bin_prob, 26 dp, 31 lngamma, 26		•
particles, 20     psi, 20     qscale, 21     rho, 21     talagrand, 21     time_bwn_obs, 21     timestep, 21     type, 21     use_mean, 22     use_traj, 22     use_weak, 22     qdata, 24     quicksort.f90     quicksort_d, 80     quicksort_d     quicksort.f90, 80     quicksort.f90, 80     qval     qdata, 24     ruse_tsisf90, 40     random, 25     bin_prob, 26     dp, 31     lngamma, 26	nudgefac, 20	•
psi, 20 qscale, 21 rho, 21 time, 21 time_bwn_obs, 21 timestep, 21 type, 21 ufac, 22 use_traj, 22 use_traj, 22 use_weak, 22  quicksort.f90 quicksort_d, 80 quicksort_d quicksort.f90, 80 quicksort.f90, 80 quicksort.f90, 80 qual qdata, 24  r qdata, 24  r model_specific.f90, 40 r-tests tests.f90, 74 random, 25 bin_prob, 26 dp, 31 lngamma, 26	particles, 20	
qscale, 21       insertionsort_d, 80         rho, 21       quicksort_d, 80         talagrand, 21       quicksort_d         time, 21       quicksort.f90, 80         time_bwn_obs, 21       qval         time_obs, 21       qdata, 24         timestep, 21       r         type, 21       r         ufac, 22       model_specific.f90, 40         use_mean, 22       r_tests         use_rmse, 22       tests.f90, 74         use_talagrand, 22       random, 25         use_traj, 22       bin_prob, 26         use_var, 22       dp, 31         use_weak, 22       lngamma, 26	psi, 20	•
rho, 21 talagrand, 21 time, 21 time, 21 time_bwn_obs, 21 time_obs, 21 timestep, 21 type, 21 ufac, 22 use_mean, 22 use_traj, 22 use_weak, 22  requicksort_d quicksort.f90, 80 qual quicksort.f90, 80 qval qdata, 24  requicksort_d quicksort_d quicksort_f90, 80 qval requicksort_f90, 80 qval	qscale, 21	
time, 21 quicksort.f90, 80 time_bwn_obs, 21 qval time_obs, 21 qdata, 24 timestep, 21 type, 21 r model_specific.f90, 40 use_mean, 22 r_tests use_rmse, 22 tests.f90, 74 use_talagrand, 22 random, 25 use_traj, 22 bin_prob, 26 use_var, 22 dp, 31 use_weak, 22 lngamma, 26	rho, 21	
time_bwn_obs, 21 time_obs, 21 time_obs, 21 timestep, 21 type, 21 ufac, 22 use_mean, 22 use_talagrand, 22 use_traj, 22 use_var, 22 use_weak, 22  reval qdata, 24  remodel_specific.f90, 40 r_tests tests.f90, 74 random, 25 bin_prob, 26 dp, 31 lngamma, 26	talagrand, 21	quicksort_d
time_obs, 21 timestep, 21 type, 21 rufac, 22 use_mean, 22 use_talagrand, 22 use_traj, 22 use_var, 22 use_weak, 22 rqdata, 24 r qdata, 24 r qdata, 24 r qdata, 24 r r r total r type, 21 r model_specific.f90, 40 r r_tests rests.f90, 74 random, 25 bin_prob, 26 dp, 31 lngamma, 26	time, 21	quicksort.f90, 80
timestep, 21 type, 21 rufac, 22 use_mean, 22 use_rmse, 22 use_talagrand, 22 use_traj, 22 use_var, 22 use_weak, 22 rests rests rests.f90, 74 random, 25 bin_prob, 26 dp, 31 use_weak, 22 lngamma, 26	time_bwn_obs, 21	qval
type, 21 r ufac, 22 model_specific.f90, 40 use_mean, 22 r_tests use_rmse, 22 tests.f90, 74 use_talagrand, 22 random, 25 use_traj, 22 bin_prob, 26 use_var, 22 dp, 31 use_weak, 22 lngamma, 26		qdata, 24
ufac, 22       model_specific.f90, 40         use_mean, 22       r_tests         use_rmse, 22       tests.f90, 74         use_talagrand, 22       random, 25         use_traj, 22       bin_prob, 26         use_var, 22       dp, 31         use_weak, 22       lngamma, 26	•	
use_mean, 22       r_tests         use_rmse, 22       tests.f90, 74         use_talagrand, 22       random, 25         use_traj, 22       bin_prob, 26         use_var, 22       dp, 31         use_weak, 22       lngamma, 26		
use_rmse, 22       tests.f90, 74         use_talagrand, 22       random, 25         use_traj, 22       bin_prob, 26         use_var, 22       dp, 31         use_weak, 22       lngamma, 26		— ·
use_talagrand, 22 random, 25 use_traj, 22 bin_prob, 26 use_var, 22 dp, 31 use_weak, 22 lngamma, 26		<del>-</del>
use_traj, 22       bin_prob, 26         use_var, 22       dp, 31         use_weak, 22       Ingamma, 26		•
use_var, 22 dp, 31 use_weak, 22 Ingamma, 26	_ <del>-</del>	
use_weak, 22 Ingamma, 26		<del>_</del>
<del>-</del>		•
weight, 22 random_beta, 26		_
	weigiit, ZZ	random_beta, 20

random_binomial1, 26	rank_hist_nums
random_binomial2, 27	histogram_data, 12
random_cauchy, 27	rcol
random_chisq, 27	rdata, <mark>32</mark>
random_exponential, 27	rdata, 31
random_gamma, 27	killr, 32
random_gamma1, 28	loadr, 32
random_gamma2, 28	rcol, 32
random_inv_gauss, 29	rdiag, 32
random_mvnorm, 29	rn, <mark>32</mark>
random neg binomial, 29	rne, <mark>32</mark>
random_normal, 29	rrow, 33
random_order, 30	rval, <mark>33</mark>
random_poisson, 30	rdiag
random t, 30	rdata, 32
random von mises, 30	resample
random_weibull, 30	resample.f90, 66
seed random number, 31	resample.f90
random_beta	resample, 66
random, 26	rhalf
random binomial1	model specific.f90, 41
_	rhl n
random, 26	histogram_data, 12
random_binomial2	rhn n
random, 27	histogram_data, 12
random_cauchy	rho
random, 27	pf_control::pf_control_type, 21
random_chisq	rn
random, 27	rdata, 32
random_exponential	•
random, 27	rne
random_gamma	rdata, 32
random, 27	rrow
random_gamma1	rdata, 33
random, 28	rval
random_gamma2	rdata, 33
random, 28	save observation data
random_inv_gauss	data io.f90, 77
random, 29	save state
random_mvnorm	data io.f90, 77
random, 29	save_truth
random_neg_binomial	data io.f90, 78
random, 29	seed_random_number
random_normal	random, 31
random, 29	set_pf_controls
random order	pf control, 16
random, 30	sir filter
random_poisson	sir filter.f90, 53
random, 30	sir_filter.f90
random_seed_mpi	sir filter, 53
gen_rand.f90, 60	<del>-</del> · · ·
random t	sizes, 33
random, 30	obs_dim, 33
	state_dim, 33
random_von_mises	solve_hqht_plus_r
random, 30	model_specific.f90, 42
random_weibull	solve_r
random, 30	model_specific.f90, 42
rank_hist_list	solve_rhalf
histogram_data, 12	model_specific.f90, 43

solve_rhalf_local	test_r.f90
enkf_specific.f90, 48	test_r, 70
src/DOC_README.txt, 46	tests.f90
src/controlers/pf_control.f90, 44	h_tests, 71
src/controlers/pf_couple.f90, 44	hqhtr_tests, 72
src/controlers/pf_parameters.dat, 45	q_tests, 73
src/controlers/sizes.f90, 45	r_tests, 74
src/data/Qdata.f90, 46	time
src/data/Rdata.f90, 46	pf_control::pf_control_type, 21
src/filters/deterministic model.f90, 46	time_bwn_obs
src/filters/eakf_analysis.f90, 46	pf_control::pf_control_type, 21
src/filters/enkf_specific.f90, 47	time obs
src/filters/equivalent_weights_step.f90, 49	pf_control::pf_control_type, 21
src/filters/etkf_analysis.f90, 50	timestep
src/filters/letkf_analysis.f90, 51	pf_control::pf_control_type, 21
src/filters/proposal_filter.f90, 52	trajectories
src/filters/sir_filter.f90, 53	diagnostics.f90, 79
src/filters/stochastic_model.f90, 54	type
src/operations/gen_rand.f90, 55	pf_control::pf_control_type, 21
src/operations/operator_wrappers.f90, 61	pcoopcooypo,
src/operations/perturb_particle.f90, 64	ufac
src/operations/resample.f90, 66	pf_control::pf_control_type, 22
src/tests/alltests.f90, 67	uniformrandomnumbers1d
src/tests/test_h.f90, 67	gen_rand.f90, 60
src/tests/test_hqhtr.f90, 68	update_state
src/tests/test_q.f90, 69	perturb_particle.f90, 65
src/tests/test_r.f90, 70	use mean
src/tests/tests.f90, 71	pf_control::pf_control_type, 22
src/utils/comms.f90, 75	use rmse
src/utils/data_io.f90, 75	pf_control::pf_control_type, 22
src/utils/data_10.190, 73 src/utils/diagnostics.f90, 78	use_talagrand
	pf_control::pf_control_type, 22
src/utils/genQ.f90, 79	use_traj
src/utils/histogram.f90, 80	pf_control::pf_control_type, 22
src/utils/quicksort.f90, 80	use_var
src/utils/random_d.f90, 82	pf_control::pf_control_type, 22
state_dim	use weak
sizes, 33	pf_control::pf_control_type, 22
stochastic_model	pi_controlpi_control_type, 22
stochastic_model.f90, 54	weight
stochastic_model.f90	pf_control::pf_control_type, 22
check_scaling, 54	pcom.cmpcom.ctype, ==
stochastic_model, 54	
talagrand	
pf control::pf control type, 21	
test h	
test h.f90, 68	
test_h.f90	
test_h, 68	
test_hqhtr	
_ ·	
test_hghtr.f90, 68	
test_hqhtr.f90	
test_hqhtr, 68	
test_q	
test_q.f90, 69	
test_q.f90	
test_q, 69	
test_r	
test_r.f90, <del>70</del>	