Instructions for generating plots shown in paper, "The 'ABC-DA' system (v1.4): a variational data assimilation system for convective scale research with a study of the impact of a balance constraint"

#### January 17, 2020

Further guidance on downloading, compiling, and running the software is available in the documentation on github (DOI: 10.5281/zenodo.3531926). The mentioned document also shows how the python plotting code is accessed.

### 1 Figure 1

This is a schema, and so doesn't require production of any results.

### 2 Figure 2

- 1. This requires the control variable transform (CVT) to first be calibrated. Make directory to contain CVT.nc file (call Master\_Calibration), and enter this directory.
- 2. Make directory inside Master\_Calibration (call Master\_Calibration\_stage1) and enter this directory.
- 3. Generate ensemble to be used for calibrating the CVT from given UM file (Member001.nc inside directory /home/data/UMdir in this example). Run Master\_Calibration.out with the following namelist file present (User Options.nl). See documentation, §4.4.1.

```
&UserOptions
! Reading and processing UM data
Α
                          = 0.02,
В
                          = 0.01,
\mathbf{C}
                          = 1.0 \,\mathrm{E4}
dt
                          = 4.0,
Adv_tracer
                         = .TRUE.
runlength
                         = 3600.0,
CalibRunStage
                         = 1,
NEns
                         = 1,
EnsDirs (1)
                         = '/home/data/UMdir',
                         = 1,
NEnsMems
NNMC
                          = 0,
Nlats
                          = 260,
latindex (1)
                          = 11,
latindex(2)
                          = 12,
latindex (3)
                          = 13,
latindex (4)
                          = 14,
latindex (5)
                          = 15,
latindex (6)
                         = 16,
latindex(7)
                         = 17,
latindex (8)
                         = 18,
latindex (9)
                         = 19,
latindex (10)
                         = 20,
latindex (11)
                         = 21,
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latindex (12)	$=  2 2 \; ,$
latindex (13)	= 23,
latindex (14)	= 24,
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latindex (15)	$=\ 25\ ,$
latindex (16)	=26,
latindex (17)	=  2 7  ,
latindex (18)	=28,
latindex (19)	$=\;29,$
latindex (20)	=~30,
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latindex (21)	=~31~,
latindex (22)	=~32~,
latindex (23)	= 33,
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latindex (29)	=39,
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latindex (31)	= 41,
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latindex (32)	$= \ 42 \ ,$
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latindex (41)	= 51,
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latindex (43)	
latindex (44)	= 54,
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latindex (45)	
latindex (46)	= 56,
latindex (47)	= 57,
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latindex (49)	= 59,
latindex (50)	= 60,
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latindex (51)	,
latindex (52)	= 62,
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latindex (53)	= 63,
latindex (54)	= 64,
latindex (55)	= 65 ,
latindex (56)	= 66,
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latindex (57) latindex (58) latindex (59) latindex (60)	= 67, $= 68,$ $= 69,$ $= 70,$
latindex (57) latindex (58) latindex (59) latindex (60) latindex (61)	$egin{array}{lll} = & 67 , \\ = & 68 , \\ = & 69 , \\ = & 70 , \\ = & 71 , \end{array}$
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latindex (57) latindex (58) latindex (59) latindex (60) latindex (61) latindex (62)	$egin{array}{lll} = & 67, \\ = & 68, \\ = & 69, \\ = & 70, \\ = & 71, \\ = & 72, \end{array}$
latindex (57) latindex (58) latindex (59) latindex (60) latindex (61) latindex (62) latindex (63)	$egin{array}{lll} = & 67 , \\ = & 68 , \\ = & 69 , \\ = & 70 , \\ = & 71 , \\ = & 72 , \\ = & 73 , \end{array}$
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latindex (57) latindex (58) latindex (59) latindex (60) latindex (61) latindex (62) latindex (63) latindex (64)	$egin{array}{lll} = & 67 , \\ = & 68 , \\ = & 69 , \\ = & 70 , \\ = & 71 , \\ = & 72 , \\ = & 73 , \\ = & 74 , \end{array}$
latindex (57) latindex (58) latindex (59) latindex (60) latindex (61) latindex (62) latindex (63) latindex (64) latindex (65)	$egin{array}{lll} = & 67 , \\ = & 68 , \\ = & 69 , \\ = & 70 , \\ = & 71 , \\ = & 72 , \\ = & 73 , \\ = & 74 , \\ = & 75 , \\ \end{array}$
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latindex (57) latindex (58) latindex (59) latindex (60) latindex (61) latindex (62) latindex (63) latindex (64) latindex (65) latindex (66)	$egin{array}{lll} = 67 , \\ = 68 , \\ = 69 , \\ = 70 , \\ = 71 , \\ = 72 , \\ = 73 , \\ = 74 , \\ = 75 , \\ = 76 , \end{array}$
latindex (57) latindex (58) latindex (59) latindex (60) latindex (61) latindex (62) latindex (63) latindex (64) latindex (65)	$egin{array}{lll} = & 67 , \\ = & 68 , \\ = & 69 , \\ = & 70 , \\ = & 71 , \\ = & 72 , \\ = & 73 , \\ = & 74 , \\ = & 75 , \\ \end{array}$
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latindex (57) latindex (58) latindex (59) latindex (60) latindex (61) latindex (62) latindex (63) latindex (64) latindex (65) latindex (66) latindex (67) latindex (68)	$egin{array}{lll} = 67 , \\ = 68 , \\ = 69 , \\ = 70 , \\ = 71 , \\ = 72 , \\ = 73 , \\ = 74 , \\ = 75 , \\ = 76 , \\ = 77 , \\ = 78 , \end{array}$
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latindex (73)	latindex (74)       = 84,         latindex (75)       = 85,         latindex (76)       = 86,         latindex (78)       = 88,         latindex (79)       = 89,         latindex (80)       = 90,         latindex (80)       = 90,         latindex (81)       = 91,         latindex (82)       = 92,         latindex (83)       = 93,         latindex (84)       = 94,         latindex (85)       = 95,         latindex (86)       = 96,         latindex (87)       = 97,         latindex (89)       = 99,         latindex (89)       = 99,         latindex (90)       = 100,         latindex (91)       = 101,         latindex (91)       = 102,         latindex (91)       = 102,         latindex (93)       = 103,         latindex (94)       = 104,         latindex (95)       = 105,         latindex (96)       = 106,         latindex (97)       = 107,         latindex (98)       = 108,         latindex (100)       = 110,         latindex (101)       = 111,         latindex (104)       = 114, <t< th=""><th></th><th></th></t<>		
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latindex (82)	latindex (82)       = 92,         latindex (83)       = 93,         latindex (84)       = 94,         latindex (85)       = 95,         latindex (86)       = 96,         latindex (87)       = 97,         latindex (88)       = 98,         latindex (89)       = 99,         latindex (90)       = 100,         latindex (91)       = 101,         latindex (92)       = 102,         latindex (93)       = 103,         latindex (93)       = 104,         latindex (94)       = 104,         latindex (95)       = 105,         latindex (96)       = 106,         latindex (97)       = 107,         latindex (98)       = 108,         latindex (99)       = 109,         latindex (100)       = 110,         latindex (101)       = 111,         latindex (102)       = 112,         latindex (103)       = 113,         latindex (104)       = 114,         latindex (105)       = 115,         latindex (106)       = 116,         latindex (107)       = 117,         latindex (110)       = 122,         latindex (111)       = 122,	latindex (81)	= 91,
latindex (83)       = 93,         latindex (84)       = 94,         latindex (85)       = 95,         latindex (86)       = 96,         latindex (87)       = 97,         latindex (88)       = 98,         latindex (89)       = 99,         latindex (90)       = 100,         latindex (91)       = 101,         latindex (92)       = 102,         latindex (93)       = 103,         latindex (94)       = 104,         latindex (95)       = 105,         latindex (96)       = 106,         latindex (97)       = 107,         latindex (98)       = 108,         latindex (100)       = 110,         latindex (101)       = 111,         latindex (103)       = 113,         latindex (104)       = 114,         latindex (105)       = 115,         latindex (106)       = 116,         latindex (107)       = 117,         latindex (108)       = 118,         latindex (110)       = 112,         latindex (111)       = 120,         latindex (111)       = 122,         latindex (114)       = 122,         latindex (115)       = 125, <td>latindex (83)       = 93,         latindex (84)       = 94,         latindex (85)       = 95,         latindex (86)       = 96,         latindex (87)       = 97,         latindex (88)       = 98,         latindex (89)       = 99,         latindex (90)       = 100,         latindex (91)       = 101,         latindex (92)       = 102,         latindex (93)       = 103,         latindex (93)       = 103,         latindex (94)       = 104,         latindex (95)       = 105,         latindex (96)       = 106,         latindex (97)       = 105,         latindex (98)       = 108,         latindex (99)       = 109,         latindex (100)       = 110,         latindex (101)       = 111,         latindex (102)       = 112,         latindex (103)       = 113,         latindex (104)       = 114,         latindex (105)       = 115,         latindex (106)       = 116,         latindex (107)       = 117,         latindex (108)       = 118,         latindex (110)       = 122,         latindex (111)       = 122,</td> <td></td> <td></td>	latindex (83)       = 93,         latindex (84)       = 94,         latindex (85)       = 95,         latindex (86)       = 96,         latindex (87)       = 97,         latindex (88)       = 98,         latindex (89)       = 99,         latindex (90)       = 100,         latindex (91)       = 101,         latindex (92)       = 102,         latindex (93)       = 103,         latindex (93)       = 103,         latindex (94)       = 104,         latindex (95)       = 105,         latindex (96)       = 106,         latindex (97)       = 105,         latindex (98)       = 108,         latindex (99)       = 109,         latindex (100)       = 110,         latindex (101)       = 111,         latindex (102)       = 112,         latindex (103)       = 113,         latindex (104)       = 114,         latindex (105)       = 115,         latindex (106)       = 116,         latindex (107)       = 117,         latindex (108)       = 118,         latindex (110)       = 122,         latindex (111)       = 122,		
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latindex (89)       = 99,         latindex (90)       = 100,         latindex (91)       = 101,         latindex (92)       = 102,         latindex (93)       = 103,         latindex (94)       = 104,         latindex (95)       = 105,         latindex (96)       = 106,         latindex (97)       = 107,         latindex (99)       = 109,         latindex (100)       = 110,         latindex (101)       = 111,         latindex (102)       = 112,         latindex (103)       = 113,         latindex (104)       = 114,         latindex (105)       = 115,         latindex (106)       = 116,         latindex (107)       = 117,         latindex (108)       = 118,         latindex (109)       = 119,         latindex (110)       = 120,         latindex (111)       = 121,         latindex (112)       = 122,         latindex (113)       = 122,         latindex (114)       = 124,         latindex (115)       = 125,         latindex (116)       = 126,         latindex (120)       = 130,         latindex (121)       = 131, </td <td>latindex (89)       = 99,         latindex (90)       = 100,         latindex (91)       = 101,         latindex (92)       = 102,         latindex (93)       = 103,         latindex (94)       = 104,         latindex (95)       = 105,         latindex (96)       = 106,         latindex (97)       = 107,         latindex (100)       = 110,         latindex (100)       = 110,         latindex (101)       = 111,         latindex (102)       = 112,         latindex (103)       = 113,         latindex (104)       = 114,         latindex (105)       = 115,         latindex (106)       = 116,         latindex (107)       = 117,         latindex (108)       = 118,         latindex (109)       = 119,         latindex (109)       = 119,         latindex (110)       = 120,         latindex (111)       = 121,         latindex (111)       = 121,         latindex (113)       = 123,         latindex (114)       = 124,         latindex (116)       = 126,         latindex (117)       = 127,         latindex (120)       = 130,&lt;</td> <td></td> <td>- 98</td>	latindex (89)       = 99,         latindex (90)       = 100,         latindex (91)       = 101,         latindex (92)       = 102,         latindex (93)       = 103,         latindex (94)       = 104,         latindex (95)       = 105,         latindex (96)       = 106,         latindex (97)       = 107,         latindex (100)       = 110,         latindex (100)       = 110,         latindex (101)       = 111,         latindex (102)       = 112,         latindex (103)       = 113,         latindex (104)       = 114,         latindex (105)       = 115,         latindex (106)       = 116,         latindex (107)       = 117,         latindex (108)       = 118,         latindex (109)       = 119,         latindex (109)       = 119,         latindex (110)       = 120,         latindex (111)       = 121,         latindex (111)       = 121,         latindex (113)       = 123,         latindex (114)       = 124,         latindex (116)       = 126,         latindex (117)       = 127,         latindex (120)       = 130,<		- 98
latindex (90)       = 100,         latindex (91)       = 101,         latindex (92)       = 102,         latindex (93)       = 103,         latindex (94)       = 104,         latindex (95)       = 105,         latindex (96)       = 106,         latindex (97)       = 107,         latindex (98)       = 108,         latindex (100)       = 110,         latindex (101)       = 111,         latindex (102)       = 112,         latindex (103)       = 113,         latindex (104)       = 114,         latindex (105)       = 115,         latindex (106)       = 116,         latindex (107)       = 117,         latindex (108)       = 118,         latindex (109)       = 119,         latindex (111)       = 120,         latindex (111)       = 121,         latindex (111)       = 122,         latindex (111)       = 122,         latindex (113)       = 123,         latindex (114)       = 124,         latindex (115)       = 125,         latindex (118)       = 128,         latindex (120)       = 130,         latindex (121)       = 131,	latindex (90)       = 100,         latindex (91)       = 101,         latindex (92)       = 102,         latindex (93)       = 103,         latindex (94)       = 104,         latindex (95)       = 105,         latindex (96)       = 106,         latindex (97)       = 107,         latindex (98)       = 108,         latindex (100)       = 110,         latindex (101)       = 111,         latindex (102)       = 112,         latindex (103)       = 113,         latindex (104)       = 114,         latindex (105)       = 115,         latindex (106)       = 116,         latindex (107)       = 117,         latindex (108)       = 118,         latindex (109)       = 119,         latindex (110)       = 120,         latindex (111)       = 121,         latindex (112)       = 122,         latindex (113)       = 123,         latindex (114)       = 124,         latindex (115)       = 125,         latindex (116)       = 126,         latindex (120)       = 130,         latindex (121)       = 131,         latindex (122)       = 133,		
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latindex (91)	latindex (91)	latindex (90)	= 100,
latindex (92)       = 102,         latindex (93)       = 103,         latindex (95)       = 104,         latindex (95)       = 105,         latindex (97)       = 107,         latindex (98)       = 108,         latindex (100)       = 110,         latindex (101)       = 111,         latindex (102)       = 112,         latindex (103)       = 113,         latindex (104)       = 114,         latindex (105)       = 115,         latindex (106)       = 116,         latindex (107)       = 117,         latindex (108)       = 118,         latindex (109)       = 119,         latindex (110)       = 120,         latindex (111)       = 121,         latindex (112)       = 122,         latindex (113)       = 123,         latindex (114)       = 124,         latindex (115)       = 125,         latindex (116)       = 126,         latindex (117)       = 127,         latindex (119)       = 129,         latindex (120)       = 130,         latindex (121)       = 131,         latindex (122)       = 132,         latindex (123)       = 1	latindex (92)       = 102,         latindex (93)       = 103,         latindex (95)       = 104,         latindex (96)       = 106,         latindex (97)       = 107,         latindex (98)       = 108,         latindex (100)       = 110,         latindex (101)       = 111,         latindex (102)       = 112,         latindex (103)       = 113,         latindex (104)       = 114,         latindex (105)       = 115,         latindex (106)       = 116,         latindex (107)       = 117,         latindex (108)       = 118,         latindex (109)       = 119,         latindex (110)       = 120,         latindex (111)       = 121,         latindex (111)       = 122,         latindex (112)       = 122,         latindex (113)       = 123,         latindex (114)       = 124,         latindex (115)       = 125,         latindex (116)       = 126,         latindex (117)       = 127,         latindex (120)       = 130,         latindex (121)       = 131,         latindex (122)       = 132,         latindex (124)       = 1	* *	
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latindex (100)	latindex (100)	latindex (98)	
latindex (100)	latindex (100)	latindex (99)	= 109,
latindex (101)       = 111,         latindex (102)       = 112,         latindex (103)       = 113,         latindex (104)       = 114,         latindex (105)       = 115,         latindex (106)       = 116,         latindex (107)       = 117,         latindex (108)       = 118,         latindex (109)       = 119,         latindex (110)       = 120,         latindex (111)       = 121,         latindex (112)       = 122,         latindex (113)       = 123,         latindex (114)       = 124,         latindex (115)       = 125,         latindex (116)       = 126,         latindex (117)       = 127,         latindex (118)       = 128,         latindex (120)       = 130,         latindex (121)       = 131,         latindex (122)       = 132,         latindex (123)       = 133,         latindex (124)       = 134,         latindex (125)       = 135,         latindex (126)       = 136,         latindex (128)       = 138,         latindex (129)       = 139,         latindex (130)       = 140,         latindex (131)       <	latindex (101)		
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$\begin{array}{llll} \text{latindex}  (117) & = 127, \\ \text{latindex}  (118) & = 128, \\ \text{latindex}  (119) & = 129, \\ \text{latindex}  (120) & = 130, \\ \text{latindex}  (121) & = 131, \\ \text{latindex}  (122) & = 132, \\ \text{latindex}  (123) & = 133, \\ \text{latindex}  (124) & = 134, \\ \text{latindex}  (125) & = 135, \\ \text{latindex}  (125) & = 136, \\ \text{latindex}  (126) & = 136, \\ \text{latindex}  (127) & = 137, \\ \text{latindex}  (128) & = 138, \\ \text{latindex}  (129) & = 139, \\ \text{latindex}  (130) & = 140, \\ \text{latindex}  (131) & = 141, \end{array}$	$\begin{array}{llllllllllllllllllllllllllllllllllll$		
$\begin{array}{llll} \text{latindex}  (118) & = 128  , \\ \text{latindex}  (119) & = 129  , \\ \text{latindex}  (120) & = 130  , \\ \text{latindex}  (121) & = 131  , \\ \text{latindex}  (122) & = 132  , \\ \text{latindex}  (123) & = 133  , \\ \text{latindex}  (124) & = 134  , \\ \text{latindex}  (125) & = 135  , \\ \text{latindex}  (126) & = 136  , \\ \text{latindex}  (127) & = 137  , \\ \text{latindex}  (128) & = 138  , \\ \text{latindex}  (129) & = 139  , \\ \text{latindex}  (130) & = 140  , \\ \text{latindex}  (131) & = 141  , \end{array}$	$\begin{array}{llll} \text{latindex}  (118) & = 128 , \\ \text{latindex}  (119) & = 129 , \\ \text{latindex}  (120) & = 130 , \\ \text{latindex}  (121) & = 131 , \\ \text{latindex}  (122) & = 132 , \\ \text{latindex}  (123) & = 133 , \\ \text{latindex}  (124) & = 134 , \\ \text{latindex}  (125) & = 135 , \\ \text{latindex}  (126) & = 136 , \\ \text{latindex}  (127) & = 137 , \\ \text{latindex}  (128) & = 138 , \\ \text{latindex}  (129) & = 139 , \\ \text{latindex}  (130) & = 140 , \\ \text{latindex}  (131) & = 141 , \\ \text{latindex}  (132) & = 142 , \\ \end{array}$		
$\begin{array}{llll} \text{latindex}  (119) & = 129 , \\ \text{latindex}  (120) & = 130 , \\ \text{latindex}  (121) & = 131 , \\ \text{latindex}  (122) & = 132 , \\ \text{latindex}  (123) & = 133 , \\ \text{latindex}  (124) & = 134 , \\ \text{latindex}  (125) & = 135 , \\ \text{latindex}  (126) & = 136 , \\ \text{latindex}  (127) & = 137 , \\ \text{latindex}  (128) & = 138 , \\ \text{latindex}  (129) & = 139 , \\ \text{latindex}  (130) & = 140 , \\ \text{latindex}  (131) & = 141 , \end{array}$	$\begin{array}{llll} \text{latindex}  (119) & = 129 , \\ \text{latindex}  (120) & = 130 , \\ \text{latindex}  (121) & = 131 , \\ \text{latindex}  (122) & = 132 , \\ \text{latindex}  (123) & = 133 , \\ \text{latindex}  (124) & = 134 , \\ \text{latindex}  (125) & = 135 , \\ \text{latindex}  (126) & = 136 , \\ \text{latindex}  (127) & = 137 , \\ \text{latindex}  (128) & = 138 , \\ \text{latindex}  (129) & = 139 , \\ \text{latindex}  (130) & = 140 , \\ \text{latindex}  (131) & = 141 , \\ \text{latindex}  (132) & = 142 , \end{array}$		
$\begin{array}{llll} \text{latindex}  (119) & = 129 , \\ \text{latindex}  (120) & = 130 , \\ \text{latindex}  (121) & = 131 , \\ \text{latindex}  (122) & = 132 , \\ \text{latindex}  (123) & = 133 , \\ \text{latindex}  (124) & = 134 , \\ \text{latindex}  (125) & = 135 , \\ \text{latindex}  (126) & = 136 , \\ \text{latindex}  (127) & = 137 , \\ \text{latindex}  (128) & = 138 , \\ \text{latindex}  (129) & = 139 , \\ \text{latindex}  (130) & = 140 , \\ \text{latindex}  (131) & = 141 , \end{array}$	$\begin{array}{llll} \text{latindex}  (119) & = 129 , \\ \text{latindex}  (120) & = 130 , \\ \text{latindex}  (121) & = 131 , \\ \text{latindex}  (122) & = 132 , \\ \text{latindex}  (123) & = 133 , \\ \text{latindex}  (124) & = 134 , \\ \text{latindex}  (125) & = 135 , \\ \text{latindex}  (126) & = 136 , \\ \text{latindex}  (127) & = 137 , \\ \text{latindex}  (128) & = 138 , \\ \text{latindex}  (129) & = 139 , \\ \text{latindex}  (130) & = 140 , \\ \text{latindex}  (131) & = 141 , \\ \text{latindex}  (132) & = 142 , \end{array}$	latindex (118)	= 128,
$\begin{array}{lll} \text{latindex}  (120) & = 130  , \\ \text{latindex}  (121) & = 131  , \\ \text{latindex}  (122) & = 132  , \\ \text{latindex}  (123) & = 133  , \\ \text{latindex}  (124) & = 134  , \\ \text{latindex}  (125) & = 135  , \\ \text{latindex}  (126) & = 136  , \\ \text{latindex}  (127) & = 137  , \\ \text{latindex}  (128) & = 138  , \\ \text{latindex}  (129) & = 139  , \\ \text{latindex}  (130) & = 140  , \\ \text{latindex}  (131) & = 141  , \end{array}$	$\begin{array}{llll} \text{latindex}  (120) & = 130 , \\ \text{latindex}  (121) & = 131 , \\ \text{latindex}  (122) & = 132 , \\ \text{latindex}  (123) & = 133 , \\ \text{latindex}  (124) & = 134 , \\ \text{latindex}  (125) & = 135 , \\ \text{latindex}  (126) & = 136 , \\ \text{latindex}  (127) & = 137 , \\ \text{latindex}  (128) & = 138 , \\ \text{latindex}  (129) & = 139 , \\ \text{latindex}  (130) & = 140 , \\ \text{latindex}  (131) & = 141 , \\ \text{latindex}  (132) & = 142 , \end{array}$		
$\begin{array}{lll} \text{latindex}  (121) & = 131  , \\ \text{latindex}  (122) & = 132  , \\ \text{latindex}  (123) & = 133  , \\ \text{latindex}  (124) & = 134  , \\ \text{latindex}  (125) & = 135  , \\ \text{latindex}  (126) & = 136  , \\ \text{latindex}  (127) & = 137  , \\ \text{latindex}  (128) & = 138  , \\ \text{latindex}  (129) & = 139  , \\ \text{latindex}  (130) & = 140  , \\ \text{latindex}  (131) & = 141  , \end{array}$	$\begin{array}{lll} \text{latindex}  (121) & = 131 , \\ \text{latindex}  (122) & = 132 , \\ \text{latindex}  (123) & = 133 , \\ \text{latindex}  (124) & = 134 , \\ \text{latindex}  (125) & = 135 , \\ \text{latindex}  (126) & = 136 , \\ \text{latindex}  (127) & = 137 , \\ \text{latindex}  (128) & = 138 , \\ \text{latindex}  (129) & = 139 , \\ \text{latindex}  (130) & = 140 , \\ \text{latindex}  (131) & = 141 , \\ \text{latindex}  (132) & = 142 , \end{array}$		
$\begin{array}{lll} \text{latindex}  (122) & = 132  , \\ \text{latindex}  (123) & = 133  , \\ \text{latindex}  (124) & = 134  , \\ \text{latindex}  (125) & = 135  , \\ \text{latindex}  (126) & = 136  , \\ \text{latindex}  (127) & = 137  , \\ \text{latindex}  (128) & = 138  , \\ \text{latindex}  (129) & = 139  , \\ \text{latindex}  (130) & = 140  , \\ \text{latindex}  (131) & = 141  , \end{array}$	$\begin{array}{lll} \text{latindex}  (122) & = 132  , \\ \text{latindex}  (123) & = 133  , \\ \text{latindex}  (124) & = 134  , \\ \text{latindex}  (125) & = 135  , \\ \text{latindex}  (126) & = 136  , \\ \text{latindex}  (127) & = 137  , \\ \text{latindex}  (128) & = 138  , \\ \text{latindex}  (129) & = 139  , \\ \text{latindex}  (130) & = 140  , \\ \text{latindex}  (131) & = 141  , \\ \text{latindex}  (132) & = 142  , \end{array}$		
$\begin{array}{lll} \text{latindex}  (122) & = 132  , \\ \text{latindex}  (123) & = 133  , \\ \text{latindex}  (124) & = 134  , \\ \text{latindex}  (125) & = 135  , \\ \text{latindex}  (126) & = 136  , \\ \text{latindex}  (127) & = 137  , \\ \text{latindex}  (128) & = 138  , \\ \text{latindex}  (129) & = 139  , \\ \text{latindex}  (130) & = 140  , \\ \text{latindex}  (131) & = 141  , \end{array}$	$\begin{array}{lll} \text{latindex}  (122) & = 132  , \\ \text{latindex}  (123) & = 133  , \\ \text{latindex}  (124) & = 134  , \\ \text{latindex}  (125) & = 135  , \\ \text{latindex}  (126) & = 136  , \\ \text{latindex}  (127) & = 137  , \\ \text{latindex}  (128) & = 138  , \\ \text{latindex}  (129) & = 139  , \\ \text{latindex}  (130) & = 140  , \\ \text{latindex}  (131) & = 141  , \\ \text{latindex}  (132) & = 142  , \end{array}$	latindex (121)	= 131,
$\begin{array}{lll} \text{latindex}  (123) & = 133  , \\ \text{latindex}  (124) & = 134  , \\ \text{latindex}  (125) & = 135  , \\ \text{latindex}  (126) & = 136  , \\ \text{latindex}  (127) & = 137  , \\ \text{latindex}  (128) & = 138  , \\ \text{latindex}  (129) & = 139  , \\ \text{latindex}  (130) & = 140  , \\ \text{latindex}  (131) & = 141  , \end{array}$	$\begin{array}{lll} \text{latindex} \ (123) & = 133  , \\ \text{latindex} \ (124) & = 134  , \\ \text{latindex} \ (125) & = 135  , \\ \text{latindex} \ (126) & = 136  , \\ \text{latindex} \ (127) & = 137  , \\ \text{latindex} \ (128) & = 138  , \\ \text{latindex} \ (129) & = 139  , \\ \text{latindex} \ (130) & = 140  , \\ \text{latindex} \ (131) & = 141  , \\ \text{latindex} \ (132) & = 142  , \end{array}$		
$\begin{array}{lll} \text{latindex}  (124) & = 134 , \\ \text{latindex}  (125) & = 135 , \\ \text{latindex}  (126) & = 136 , \\ \text{latindex}  (127) & = 137 , \\ \text{latindex}  (128) & = 138 , \\ \text{latindex}  (129) & = 139 , \\ \text{latindex}  (130) & = 140 , \\ \text{latindex}  (131) & = 141 , \end{array}$	$\begin{array}{lll} \text{latindex}  (124) & = 134 , \\ \text{latindex}  (125) & = 135 , \\ \text{latindex}  (126) & = 136 , \\ \text{latindex}  (127) & = 137 , \\ \text{latindex}  (128) & = 138 , \\ \text{latindex}  (129) & = 139 , \\ \text{latindex}  (130) & = 140 , \\ \text{latindex}  (131) & = 141 , \\ \text{latindex}  (132) & = 142 , \end{array}$		
$\begin{array}{lll} \text{latindex}  (125) & = 135  , \\ \text{latindex}  (126) & = 136  , \\ \text{latindex}  (127) & = 137  , \\ \text{latindex}  (128) & = 138  , \\ \text{latindex}  (129) & = 139  , \\ \text{latindex}  (130) & = 140  , \\ \text{latindex}  (131) & = 141  , \end{array}$	$\begin{array}{lll} \text{latindex}  (125) & = 135  , \\ \text{latindex}  (126) & = 136  , \\ \text{latindex}  (127) & = 137  , \\ \text{latindex}  (128) & = 138  , \\ \text{latindex}  (129) & = 139  , \\ \text{latindex}  (130) & = 140  , \\ \text{latindex}  (131) & = 141  , \\ \text{latindex}  (132) & = 142  , \end{array}$		
$\begin{array}{lll} \text{latindex}  (125) & = 135  , \\ \text{latindex}  (126) & = 136  , \\ \text{latindex}  (127) & = 137  , \\ \text{latindex}  (128) & = 138  , \\ \text{latindex}  (129) & = 139  , \\ \text{latindex}  (130) & = 140  , \\ \text{latindex}  (131) & = 141  , \end{array}$	$\begin{array}{lll} \text{latindex}  (125) & = 135  , \\ \text{latindex}  (126) & = 136  , \\ \text{latindex}  (127) & = 137  , \\ \text{latindex}  (128) & = 138  , \\ \text{latindex}  (129) & = 139  , \\ \text{latindex}  (130) & = 140  , \\ \text{latindex}  (131) & = 141  , \\ \text{latindex}  (132) & = 142  , \end{array}$	$\operatorname{latindex}\left(124 ight)$	= 134,
$\begin{array}{lll} \text{latindex}  (126) & = 136 , \\ \text{latindex}  (127) & = 137 , \\ \text{latindex}  (128) & = 138 , \\ \text{latindex}  (129) & = 139 , \\ \text{latindex}  (130) & = 140 , \\ \text{latindex}  (131) & = 141 , \end{array}$	$\begin{array}{lll} \text{latindex}  (126) & = 136 , \\ \text{latindex}  (127) & = 137 , \\ \text{latindex}  (128) & = 138 , \\ \text{latindex}  (129) & = 139 , \\ \text{latindex}  (130) & = 140 , \\ \text{latindex}  (131) & = 141 , \\ \text{latindex}  (132) & = 142 , \end{array}$		
$\begin{array}{lll} {\rm latindex(127)} & = 137, \\ {\rm latindex(128)} & = 138, \\ {\rm latindex(129)} & = 139, \\ {\rm latindex(130)} & = 140, \\ {\rm latindex(131)} & = 141, \end{array}$	$\begin{array}{lll} {\rm latindex}(127) & = 137, \\ {\rm latindex}(128) & = 138, \\ {\rm latindex}(129) & = 139, \\ {\rm latindex}(130) & = 140, \\ {\rm latindex}(131) & = 141, \\ {\rm latindex}(132) & = 142, \end{array}$		
$\begin{array}{lll} {\rm latindex}(128) & = 138, \\ {\rm latindex}(129) & = 139, \\ {\rm latindex}(130) & = 140, \\ {\rm latindex}(131) & = 141, \end{array}$	$\begin{array}{lll} {\rm latindex}(128) & = 138, \\ {\rm latindex}(129) & = 139, \\ {\rm latindex}(130) & = 140, \\ {\rm latindex}(131) & = 141, \\ {\rm latindex}(132) & = 142, \end{array}$		
$\begin{array}{lll} {\rm latindex}(128) & = 138, \\ {\rm latindex}(129) & = 139, \\ {\rm latindex}(130) & = 140, \\ {\rm latindex}(131) & = 141, \end{array}$	$\begin{array}{lll} {\rm latindex}(128) & = 138, \\ {\rm latindex}(129) & = 139, \\ {\rm latindex}(130) & = 140, \\ {\rm latindex}(131) & = 141, \\ {\rm latindex}(132) & = 142, \end{array}$	latindex $(127)$	= 137,
$egin{array}{lll} { m latindex} (129) & = 139, \\ { m latindex} (130) & = 140, \\ { m latindex} (131) & = 141, \\ \end{array}$	$\begin{array}{lll} {\rm latindex}(129) & = 139, \\ {\rm latindex}(130) & = 140, \\ {\rm latindex}(131) & = 141, \\ {\rm latindex}(132) & = 142, \end{array}$		= 138.
$\begin{array}{lll} { m latindex} (130) & = 140 , \\ { m latindex} (131) & = 141 , \end{array}$	$egin{array}{lll} { m latindex} & (130) & = 140 , \\ { m latindex} & (131) & = 141 , \\ { m latindex} & (132) & = 142 , \\ \end{array}$		
latindex (131) = 141,	$     \begin{array}{ll}         & \text{latindex (131)} & = 141, \\         & \text{latindex (132)} & = 142, \\     \end{array} $		
	latindex (132) = 142,		
	latindex (132) = 142,	latindex (131)	= 141.
latindex (139) = 149			
	1301110 ex (133) = 143,		,
tatingex(133) = 143,		ratingex (133)	= 143,

latindex (134)	= 144,
$\operatorname{latindex}\left(135 ight)$	= 145 ,
latindex (136)	= 146,
$\operatorname{latindex}\left(137 ight)$	= 147,
latindex (138)	= 148,
latindex (139)	= 149,
latindex (140)	= 150,
$\operatorname{latindex}(141)$	= 151,
latindex (142)	= 152,
$\operatorname{latindex}\left(143\right)$	= 153,
latindex (144)	= 154,
$\operatorname{latindex}\left(145 ight)$	= 155,
latindex (146)	= 156,
$\operatorname{latindex}\left(147\right)$	= 157,
latindex (148)	= 158,
latindex (149)	= 159,
latindex (150)	= 160,
latindex (151)	= 161,
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latindex (152)	
$\operatorname{latindex}(153)$	= 163,
latindex (154)	= 164,
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$\operatorname{latindex}(155)$	= 165,
latindex (156)	=166,
$\operatorname{latindex}(157)$	= 167,
	= 168,
latindex (158)	
latindex (159)	= 169,
latindex (160)	= 170,
$\operatorname{latindex}(161)$	= 171,
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latindex (162)	
latindex (163)	= 173,
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latindex (165)	= 175,
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latindex (166)	
$\operatorname{latindex}\left(167\right)$	= 177,
latindex (168)	= 178,
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latindex (169)	= 179,
latindex (169)	= 179,
latindex (170)	= 180,
latindex (170)	= 180,
latindex (170) latindex (171)	= 180, $= 181,$
$\begin{array}{l} \text{latindex} \ (170) \\ \text{latindex} \ (171) \\ \text{latindex} \ (172) \end{array}$	= 180, $= 181,$ $= 182,$
$\begin{array}{l} \text{latindex} \ (170) \\ \text{latindex} \ (171) \\ \text{latindex} \ (172) \end{array}$	= 180, $= 181,$ $= 182,$
latindex (170) latindex (171) latindex (172) latindex (173)	= 180, $= 181,$ $= 182,$ $= 183,$
latindex (170) latindex (171) latindex (172) latindex (173) latindex (174)	= 180, $= 181,$ $= 182,$ $= 183,$ $= 184,$
latindex (170) latindex (171) latindex (172) latindex (173)	= 180, $= 181,$ $= 182,$ $= 183,$
latindex (170) latindex (171) latindex (172) latindex (173) latindex (174) latindex (175)	= 180, $= 181,$ $= 182,$ $= 183,$ $= 184,$ $= 185,$
latindex (170) latindex (171) latindex (172) latindex (173) latindex (174) latindex (175) latindex (176)	= 180, $= 181,$ $= 182,$ $= 183,$ $= 184,$ $= 185,$ $= 186,$
latindex (170) latindex (171) latindex (172) latindex (173) latindex (174) latindex (175)	= 180, $= 181,$ $= 182,$ $= 183,$ $= 184,$ $= 185,$
latindex (170) latindex (171) latindex (172) latindex (173) latindex (174) latindex (175) latindex (176) latindex (177)	= 180, = 181, = 182, = 183, = 184, = 185, = 186, = 187,
latindex (170) latindex (171) latindex (172) latindex (173) latindex (174) latindex (175) latindex (176) latindex (177) latindex (177)	= 180, $= 181,$ $= 182,$ $= 183,$ $= 184,$ $= 185,$ $= 186,$ $= 187,$ $= 188,$
latindex (170) latindex (171) latindex (172) latindex (173) latindex (174) latindex (175) latindex (176) latindex (177)	= 180, = 181, = 182, = 183, = 184, = 185, = 186, = 187,
latindex (170) latindex (171) latindex (172) latindex (173) latindex (174) latindex (175) latindex (176) latindex (177) latindex (178) latindex (179)	= 180, $= 181,$ $= 182,$ $= 183,$ $= 184,$ $= 185,$ $= 186,$ $= 187,$ $= 188,$ $= 189,$
latindex (170) latindex (171) latindex (172) latindex (173) latindex (174) latindex (175) latindex (176) latindex (177) latindex (178) latindex (179) latindex (180)	= 180, = 181, = 182, = 183, = 184, = 185, = 186, = 187, = 188, = 189, = 190,
latindex (170) latindex (171) latindex (172) latindex (173) latindex (174) latindex (175) latindex (176) latindex (177) latindex (178) latindex (179)	= 180, = 181, = 182, = 183, = 184, = 185, = 186, = 187, = 188, = 189, = 190, = 191,
latindex (170) latindex (171) latindex (172) latindex (173) latindex (174) latindex (175) latindex (176) latindex (177) latindex (178) latindex (179) latindex (180) latindex (181)	= 180, = 181, = 182, = 183, = 184, = 185, = 186, = 187, = 188, = 189, = 190, = 191,
latindex (170) latindex (171) latindex (172) latindex (173) latindex (174) latindex (175) latindex (176) latindex (177) latindex (178) latindex (179) latindex (180) latindex (181) latindex (182)	= 180, = 181, = 182, = 183, = 184, = 185, = 186, = 187, = 188, = 189, = 190, = 191, = 192,
latindex (170) latindex (171) latindex (172) latindex (173) latindex (174) latindex (175) latindex (176) latindex (177) latindex (178) latindex (179) latindex (180) latindex (181)	= 180, = 181, = 182, = 183, = 184, = 185, = 186, = 187, = 188, = 189, = 190, = 191, = 192, = 193,
latindex (170) latindex (171) latindex (172) latindex (173) latindex (174) latindex (175) latindex (176) latindex (177) latindex (178) latindex (179) latindex (180) latindex (181) latindex (182) latindex (183)	= 180, = 181, = 182, = 183, = 184, = 185, = 186, = 187, = 188, = 189, = 190, = 191, = 192, = 193,
latindex (170) latindex (171) latindex (172) latindex (173) latindex (174) latindex (175) latindex (176) latindex (177) latindex (178) latindex (179) latindex (180) latindex (181) latindex (182) latindex (183) latindex (184)	= 180, = 181, = 182, = 183, = 184, = 185, = 186, = 187, = 188, = 189, = 190, = 191, = 192, = 193, = 194,
latindex (170) latindex (171) latindex (172) latindex (173) latindex (174) latindex (175) latindex (176) latindex (177) latindex (178) latindex (179) latindex (180) latindex (181) latindex (182) latindex (183) latindex (184) latindex (184)	= 180, = 181, = 182, = 183, = 184, = 185, = 186, = 187, = 188, = 199, = 190, = 191, = 192, = 193, = 194, = 195,
latindex (170) latindex (171) latindex (172) latindex (173) latindex (174) latindex (175) latindex (176) latindex (177) latindex (178) latindex (179) latindex (180) latindex (181) latindex (182) latindex (183) latindex (184) latindex (184)	= 180, = 181, = 182, = 183, = 184, = 185, = 186, = 187, = 188, = 199, = 190, = 191, = 192, = 193, = 194, = 195,
latindex (170) latindex (171) latindex (172) latindex (173) latindex (174) latindex (175) latindex (176) latindex (177) latindex (178) latindex (179) latindex (180) latindex (181) latindex (182) latindex (183) latindex (184) latindex (185) latindex (185) latindex (186)	= 180, = 181, = 182, = 183, = 184, = 185, = 186, = 187, = 188, = 199, = 190, = 191, = 192, = 193, = 194, = 195, = 196,
latindex (170) latindex (171) latindex (172) latindex (173) latindex (174) latindex (175) latindex (176) latindex (177) latindex (178) latindex (179) latindex (180) latindex (181) latindex (182) latindex (183) latindex (184) latindex (185) latindex (186) latindex (187)	= 180, = 181, = 182, = 183, = 184, = 185, = 186, = 187, = 188, = 190, = 191, = 192, = 193, = 194, = 195, = 196, = 197,
latindex (170) latindex (171) latindex (172) latindex (173) latindex (174) latindex (175) latindex (176) latindex (177) latindex (178) latindex (179) latindex (180) latindex (181) latindex (182) latindex (183) latindex (184) latindex (185) latindex (186) latindex (187)	= 180, = 181, = 182, = 183, = 184, = 185, = 186, = 187, = 188, = 190, = 191, = 192, = 193, = 194, = 195, = 196, = 197,
latindex (170) latindex (171) latindex (172) latindex (173) latindex (174) latindex (175) latindex (176) latindex (177) latindex (178) latindex (179) latindex (180) latindex (181) latindex (182) latindex (183) latindex (184) latindex (184) latindex (185) latindex (186) latindex (187) latindex (187)	= 180, = 181, = 182, = 183, = 184, = 185, = 186, = 187, = 188, = 190, = 191, = 192, = 193, = 194, = 195, = 196, = 197, = 198,
latindex (170) latindex (171) latindex (172) latindex (173) latindex (174) latindex (175) latindex (176) latindex (177) latindex (178) latindex (180) latindex (181) latindex (182) latindex (183) latindex (184) latindex (185) latindex (186) latindex (187) latindex (187) latindex (188) latindex (189)	= 180, = 181, = 182, = 183, = 184, = 185, = 186, = 187, = 188, = 190, = 191, = 192, = 193, = 194, = 195, = 196, = 197, = 198, = 199,
latindex (170) latindex (171) latindex (172) latindex (173) latindex (174) latindex (175) latindex (176) latindex (177) latindex (178) latindex (179) latindex (180) latindex (181) latindex (182) latindex (183) latindex (184) latindex (184) latindex (185) latindex (186) latindex (187) latindex (187)	= 180, = 181, = 182, = 183, = 184, = 185, = 186, = 187, = 188, = 190, = 191, = 192, = 193, = 194, = 195, = 196, = 197, = 198,
latindex (170) latindex (171) latindex (172) latindex (173) latindex (174) latindex (175) latindex (176) latindex (177) latindex (178) latindex (180) latindex (180) latindex (181) latindex (182) latindex (183) latindex (184) latindex (184) latindex (185) latindex (186) latindex (187) latindex (188) latindex (189) latindex (189)	= 180, = 181, = 182, = 183, = 184, = 185, = 186, = 187, = 188, = 190, = 191, = 192, = 193, = 194, = 195, = 196, = 197, = 198, = 199, = 200,
latindex (170) latindex (171) latindex (172) latindex (173) latindex (174) latindex (175) latindex (176) latindex (177) latindex (178) latindex (180) latindex (180) latindex (181) latindex (182) latindex (183) latindex (184) latindex (185) latindex (185) latindex (186) latindex (187) latindex (188) latindex (189) latindex (190) latindex (191)	= 180, = 181, = 182, = 183, = 184, = 185, = 186, = 187, = 188, = 190, = 191, = 192, = 193, = 194, = 195, = 196, = 197, = 198, = 199, = 200, = 201,
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latindex (170) latindex (171) latindex (172) latindex (173) latindex (174) latindex (175) latindex (176) latindex (177) latindex (178) latindex (180) latindex (180) latindex (181) latindex (182) latindex (183) latindex (184) latindex (185) latindex (186) latindex (187) latindex (188) latindex (189) latindex (190) latindex (191) latindex (192)	= 180, = 181, = 182, = 183, = 184, = 185, = 186, = 187, = 188, = 190, = 191, = 192, = 193, = 194, = 195, = 196, = 197, = 198, = 199, = 200, = 201, = 202,
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latindex (170) latindex (171) latindex (172) latindex (173) latindex (174) latindex (175) latindex (176) latindex (177) latindex (178) latindex (179) latindex (180) latindex (181) latindex (182) latindex (183) latindex (184) latindex (185) latindex (186) latindex (187) latindex (188) latindex (188) latindex (189) latindex (190) latindex (191) latindex (192) latindex (193)	= 180, = 181, = 182, = 183, = 184, = 185, = 186, = 187, = 188, = 190, = 191, = 192, = 193, = 194, = 195, = 196, = 197, = 198, = 199, = 200, = 201, = 202, = 203,

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$\operatorname{latindex}\left(203 ight)$	= 213,
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$\operatorname{latindex}\left(222 ight)$	= 232,
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latindex (227)	= 237,
$\operatorname{latindex}\left(228 ight)$	=238,
$\operatorname{latindex}\left(229 ight)$	= 239,
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$ \begin{array}{l} \text{latindex} (230) \\ \text{latindex} (231) \end{array} $	
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latindex (231)	= 241,
$\operatorname{latindex}\left(231 ight) \\ \operatorname{latindex}\left(232 ight)$	$= 241, \\ = 242,$
latindex (231)	= 241,
$egin{array}{l}  ext{latindex} & (231) \  ext{latindex} & (232) \  ext{latindex} & (233) \end{array}$	$egin{array}{lll} &=&241, \\ &=&242, \\ &=&243, \end{array}$
latindex (231) latindex (232) latindex (233) latindex (234)	= 241,  = 242,  = 243,  = 244,
latindex (231) latindex (232) latindex (233) latindex (234)	= 241,  = 242,  = 243,  = 244,
latindex (231) latindex (232) latindex (233) latindex (234) latindex (235)	= 241,= 242,= 243,= 244,= 245,
latindex (231) latindex (232) latindex (233) latindex (234)	= 241,= 242,= 243,= 244,= 245,= 246,
latindex (231) latindex (232) latindex (233) latindex (234) latindex (235) latindex (236)	= 241,= 242,= 243,= 244,= 245,= 246,
latindex (231) latindex (232) latindex (233) latindex (234) latindex (235) latindex (236) latindex (237)	= 241, = 242, = 243, = 244, = 245, = 246, = 247,
latindex (231) latindex (232) latindex (233) latindex (234) latindex (235) latindex (236)	= 241,= 242,= 243,= 244,= 245,= 246,
latindex (231) latindex (232) latindex (233) latindex (234) latindex (235) latindex (236) latindex (237) latindex (238)	= 241, $= 242,$ $= 243,$ $= 244,$ $= 245,$ $= 246,$ $= 247,$ $= 248,$
latindex (231) latindex (232) latindex (233) latindex (234) latindex (235) latindex (236) latindex (237) latindex (238) latindex (239)	= 241, $= 242,$ $= 243,$ $= 244,$ $= 245,$ $= 246,$ $= 247,$ $= 248,$ $= 249,$
latindex (231) latindex (232) latindex (233) latindex (234) latindex (235) latindex (236) latindex (237) latindex (238) latindex (239)	= 241, $= 242,$ $= 243,$ $= 244,$ $= 245,$ $= 246,$ $= 247,$ $= 248,$ $= 249,$
latindex (231) latindex (232) latindex (233) latindex (234) latindex (235) latindex (236) latindex (237) latindex (238) latindex (239) latindex (240)	= 241, $= 242,$ $= 243,$ $= 244,$ $= 245,$ $= 246,$ $= 247,$ $= 248,$ $= 249,$ $= 250,$
latindex (231) latindex (232) latindex (233) latindex (234) latindex (235) latindex (236) latindex (237) latindex (238) latindex (239)	= 241, $= 242,$ $= 243,$ $= 244,$ $= 245,$ $= 246,$ $= 247,$ $= 248,$ $= 249,$
latindex (231) latindex (232) latindex (233) latindex (234) latindex (235) latindex (236) latindex (237) latindex (238) latindex (239) latindex (240) latindex (241)	= 241, $= 242,$ $= 243,$ $= 244,$ $= 245,$ $= 246,$ $= 247,$ $= 248,$ $= 249,$ $= 250,$ $= 251,$
latindex (231) latindex (232) latindex (233) latindex (234) latindex (235) latindex (236) latindex (237) latindex (238) latindex (239) latindex (240) latindex (241) latindex (242)	= 241, $= 242,$ $= 243,$ $= 244,$ $= 245,$ $= 246,$ $= 247,$ $= 248,$ $= 249,$ $= 250,$ $= 251,$ $= 252,$
latindex (231) latindex (232) latindex (233) latindex (234) latindex (235) latindex (236) latindex (237) latindex (238) latindex (239) latindex (240) latindex (241) latindex (242)	= 241, $= 242,$ $= 243,$ $= 244,$ $= 245,$ $= 246,$ $= 247,$ $= 248,$ $= 249,$ $= 250,$ $= 251,$ $= 252,$
latindex (231) latindex (232) latindex (233) latindex (234) latindex (235) latindex (236) latindex (237) latindex (238) latindex (240) latindex (241) latindex (242) latindex (243)	= 241, $= 242,$ $= 243,$ $= 244,$ $= 246,$ $= 247,$ $= 248,$ $= 249,$ $= 250,$ $= 251,$ $= 252,$ $= 253,$
latindex (231) latindex (232) latindex (233) latindex (234) latindex (235) latindex (236) latindex (237) latindex (238) latindex (239) latindex (240) latindex (241) latindex (242)	$egin{array}{l} = 241, \\ = 242, \\ = 243, \\ = 244, \\ = 245, \\ = 246, \\ = 247, \\ = 248, \\ = 249, \\ = 250, \\ = 251, \\ = 252, \\ = 253, \\ = 254, \end{array}$
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latindex (231) latindex (232) latindex (233) latindex (234) latindex (235) latindex (236) latindex (237) latindex (238) latindex (239) latindex (240) latindex (241) latindex (242) latindex (243) latindex (243) latindex (244) latindex (245)	= 241, $= 242,$ $= 243,$ $= 244,$ $= 245,$ $= 246,$ $= 247,$ $= 248,$ $= 249,$ $= 250,$ $= 251,$ $= 252,$ $= 253,$ $= 254,$ $= 255,$
latindex (231) latindex (232) latindex (233) latindex (234) latindex (235) latindex (236) latindex (237) latindex (238) latindex (239) latindex (240) latindex (241) latindex (242) latindex (242) latindex (243) latindex (244)	$egin{array}{l} = 241, \\ = 242, \\ = 243, \\ = 244, \\ = 245, \\ = 246, \\ = 247, \\ = 248, \\ = 249, \\ = 250, \\ = 251, \\ = 252, \\ = 253, \\ = 254, \end{array}$
latindex (231) latindex (232) latindex (233) latindex (234) latindex (235) latindex (236) latindex (237) latindex (238) latindex (239) latindex (240) latindex (241) latindex (241) latindex (242) latindex (243) latindex (244) latindex (245) latindex (245) latindex (246)	= 241, $= 242,$ $= 243,$ $= 244,$ $= 245,$ $= 246,$ $= 247,$ $= 248,$ $= 249,$ $= 250,$ $= 251,$ $= 252,$ $= 253,$ $= 254,$ $= 256,$
latindex (231) latindex (232) latindex (233) latindex (234) latindex (235) latindex (236) latindex (237) latindex (238) latindex (239) latindex (240) latindex (241) latindex (241) latindex (242) latindex (243) latindex (244) latindex (245) latindex (246) latindex (246) latindex (247)	= 241, $= 242,$ $= 243,$ $= 244,$ $= 245,$ $= 246,$ $= 247,$ $= 248,$ $= 249,$ $= 250,$ $= 251,$ $= 252,$ $= 253,$ $= 254,$ $= 256,$ $= 257,$
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latindex (231) latindex (232) latindex (233) latindex (234) latindex (235) latindex (236) latindex (237) latindex (238) latindex (239) latindex (240) latindex (241) latindex (241) latindex (242) latindex (243) latindex (243) latindex (244) latindex (245) latindex (246) latindex (247) latindex (247)	= 241, $= 242,$ $= 243,$ $= 244,$ $= 245,$ $= 246,$ $= 249,$ $= 250,$ $= 251,$ $= 252,$ $= 253,$ $= 254,$ $= 256,$ $= 257,$ $= 258,$
latindex (231) latindex (232) latindex (233) latindex (234) latindex (235) latindex (236) latindex (237) latindex (238) latindex (239) latindex (240) latindex (241) latindex (241) latindex (242) latindex (243) latindex (244) latindex (245) latindex (246) latindex (246) latindex (247)	= 241, $= 242,$ $= 243,$ $= 244,$ $= 245,$ $= 246,$ $= 247,$ $= 248,$ $= 249,$ $= 250,$ $= 251,$ $= 252,$ $= 253,$ $= 254,$ $= 256,$ $= 257,$
latindex (231) latindex (232) latindex (233) latindex (234) latindex (235) latindex (236) latindex (237) latindex (238) latindex (239) latindex (240) latindex (241) latindex (241) latindex (242) latindex (243) latindex (243) latindex (244) latindex (245) latindex (246) latindex (247) latindex (248) latindex (248)	= 241, $= 242,$ $= 243,$ $= 244,$ $= 245,$ $= 246,$ $= 249,$ $= 250,$ $= 251,$ $= 252,$ $= 253,$ $= 254,$ $= 255,$ $= 256,$ $= 257,$ $= 258,$ $= 259,$
latindex (231) latindex (232) latindex (233) latindex (234) latindex (235) latindex (236) latindex (237) latindex (238) latindex (239) latindex (240) latindex (241) latindex (242) latindex (242) latindex (243) latindex (244) latindex (245) latindex (246) latindex (247) latindex (248) latindex (248) latindex (249) latindex (250)	= 241, $= 242,$ $= 243,$ $= 244,$ $= 245,$ $= 246,$ $= 247,$ $= 248,$ $= 250,$ $= 251,$ $= 252,$ $= 253,$ $= 254,$ $= 255,$ $= 256,$ $= 257,$ $= 258,$ $= 259,$ $= 260,$
latindex (231) latindex (232) latindex (233) latindex (234) latindex (235) latindex (236) latindex (237) latindex (238) latindex (239) latindex (240) latindex (241) latindex (242) latindex (242) latindex (243) latindex (244) latindex (245) latindex (246) latindex (247) latindex (248) latindex (248) latindex (249) latindex (250)	= 241, $= 242,$ $= 243,$ $= 244,$ $= 245,$ $= 246,$ $= 249,$ $= 250,$ $= 251,$ $= 252,$ $= 253,$ $= 254,$ $= 255,$ $= 256,$ $= 257,$ $= 258,$ $= 259,$
latindex (231) latindex (232) latindex (233) latindex (234) latindex (235) latindex (236) latindex (237) latindex (238) latindex (239) latindex (240) latindex (241) latindex (242) latindex (242) latindex (243) latindex (244) latindex (245) latindex (246) latindex (247) latindex (247) latindex (248) latindex (249) latindex (250) latindex (251)	= 241, $= 242,$ $= 243,$ $= 244,$ $= 245,$ $= 246,$ $= 247,$ $= 248,$ $= 250,$ $= 251,$ $= 252,$ $= 253,$ $= 254,$ $= 255,$ $= 256,$ $= 259,$ $= 260,$ $= 261,$
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latindex (231) latindex (232) latindex (233) latindex (234) latindex (235) latindex (236) latindex (237) latindex (238) latindex (239) latindex (240) latindex (241) latindex (242) latindex (242) latindex (243) latindex (244) latindex (245) latindex (246) latindex (247) latindex (247) latindex (248) latindex (249) latindex (250) latindex (251) latindex (252) latindex (253) latindex (254)	= 241, $= 242,$ $= 243,$ $= 244,$ $= 245,$ $= 246,$ $= 247,$ $= 248,$ $= 250,$ $= 251,$ $= 252,$ $= 253,$ $= 254,$ $= 255,$ $= 256,$ $= 257,$ $= 260,$ $= 261,$ $= 262,$ $= 264,$
latindex (231) latindex (232) latindex (233) latindex (234) latindex (235) latindex (236) latindex (237) latindex (238) latindex (239) latindex (240) latindex (241) latindex (242) latindex (242) latindex (244) latindex (244) latindex (245) latindex (246) latindex (247) latindex (248) latindex (248) latindex (249) latindex (250) latindex (251) latindex (252) latindex (253)	= 241, $= 242,$ $= 243,$ $= 244,$ $= 245,$ $= 246,$ $= 247,$ $= 248,$ $= 250,$ $= 251,$ $= 252,$ $= 253,$ $= 254,$ $= 255,$ $= 256,$ $= 257,$ $= 258,$ $= 260,$ $= 261,$ $= 262,$ $= 263,$

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latindex (257)
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latindex (258)
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latindex (259)
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latindex (260)
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datadirABCfcs
datadirCVT
CVT file
                       = 'CVT. nc',
CVT%CVT order
                       = 1,
CVT\%CVT_param_opt_gb = 1,
CVT\%CVT param opt hb = 1,
CVT\%CVT_param_opt_ab = 2,
CVT\%CVT_param_opt_reg = 1,
CVT\%CVT\_vert\_opt\_sym = 1,
CVT%CVT_stddev_opt
```

- 4. Make directory inside Master Calibration (call Master Calibration stage2) and enter this directory.
- 5. Generate ensemble mean state, and perturbations from this ensemble. Run *Master\_Calibration.out* with the following namelist file present (*UserOptions.nl*). See documentation, §4.4.2.

```
&UserOptions
! Generating ensemble perturbations from ensemble forecasts
CalibRunStage
                  = 2,
NEns
                  = 1,
                  = 1,
NEnsMems
NNMC
                  = 0,
                  = 260,
Nlats
                  = '... / Master_Calibration_stage1',
datadirABCfcs
                 datadirABCperts
datadirCVT
CVT file
                  = 'CVT. nc'
```

- 6. Make directory inside Master\_Calibration (call Master\_Calibration\_stage3) and enter this directory.
- 7. Generate vertical regression matrix. Run Master\_Calibration.out with the following namelist file present (UserOptions.nl). See documentation, §4.4.3.

```
&UserOptions
! Generate vertical regression matrix
CalibRunStage
                  =3,
NEns
                  = 1,
                  = 1,
NEnsMems
NNMC
                  = 0,
Nlats
                  = 260,
datadirRegression = '.',
datadirABCperts = '.../ Master_Calibration_stage2',
datadirCVT
CVT file
                  = 'CVT. nc'
```

- 8. To plot figure 2(c), edit the python program *PlotRegressionMatrices.py* to set *datadirCVT* to *Master\_Calibration*, and run the python program.
- 9. Make directory inside Master\_Calibration (call Master\_Calibration\_stage4) and enter this directory.

10. Generate ensemble perturbations in terms of parameters. Run Master\_Calibration.out with the following namelist file present (UserOptions.nl). See documentation, §4.4.4.

```
&UserOptions
! Generate parameter perturbations
CalibRunStage
                   =4,
NEns
                   = 1,
NEnsMems
                   = 1,
NNMC
                   = 0,
Nlats
                   = 260,
                   = '... | Master Calibration stage2',
datadirABCperts
datadir Con Params\\
datadirCVT
CVT file
                   = 'CVT. nc',
```

11. To plot Figs. 2(a,b,d), edit the python program  $Plot\_rp\_pre+post\_regress.py$  to set  $data\_dir\_stage2$  to  $Master\_Calibration/Master\_Calibration\_stage2$  and  $data\_dir\_stage4$  to  $Master\_Calibration/Master\_Calibration\_stage2$  and run the python program.

### 3 Figure 3

- 1. Make directory inside Master\_Calibration (call Master\_Calibration\_stage5) and enter this directory.
- 2. Generate spatial transform data (the remaining part of the calibration step). Run Master\_Calibration.out with the following namelist file present (UserOptions.nl). See documentation, §4.4.5.

```
&UserOptions
! Calibrate spatial transforms
CalibRunStage
                   = 5,
NEns
                   = 1,
NEnsMems
                   = 1,
NNMC
                   = 0,
                   = 260,
Nlats
datadirABCperts
                     '../ Master_Calibration_stage2',
datadir Con Params
                   = '... | Master_Calibration_stage4',
datadirCVT
CVT file
                   = 'CVT. nc'
```

- 3. Edit the python program PlotCVT.py to set  $data\_dir\_CVT$  to  $Master\_Calibration$ , and run the python program.
- 4. This can be repeated for different experiment configurations to get the different lines in panel (c) of the paper.

# 4 Figure 4

- 1. This is also output from PlotCVT.py as run for Fig. 3.
- 2. This can be repeated for different experiment configurations to get the different lines in panel (c) of the paper.

# 5 Figure 5

1. This is also output from PlotCVT.py as run for Fig. 3.

### 6 Figure 6

1. This plot requires the same data as used for Fig. 5, plus knowledge of the gravity wave speeds (found from a linear analysis). Run a linear analysis of the model by first creating a directory  $Master\_Linear\_Analysis$  (in the same place as directory  $Master\_Calibration$ ) and enter this directory. Run  $Master\_Linear\_Analysis.out$  with the following namelist file present (UserOptions.nl). See documentation, §4.3.

#### 

2. Compile the c++ program RossbyRadius.cpp (contained in the same directory as the python plotting code, note the libraries that are required):

3. Run this code as follows from the command line inside directory Master\_Linear\_Analysis:

```
./RossbyRadius.out ../Master Calibration .
```

4. To plot Fig. 6, edit the python program  $Plot\_horizvars\_unbalrho+Rossby.py$  to set  $CVT\_file$  to  $Master\_Linear\_Analysis/VerticalModeCharacteristics.dat$  and run the python program.

# 7 Figure 7

1. Make a directory  $Master\_ImpliedCovs$  (in the same place as directory  $Master\_Calibration$ ) and enter this directory. Run  $Master\_ImpliedCov.out$  with the following namelist file present (UserOptions.nl). See documentation, §4.6.

```
&UserOptions
 Compute implied covariances
  datadirImpliedCov
                             = '../Master_Calibration',
  datadirCVT
  {
m CVT} file
                             = 'CVT. nc',
                             = '... / Master Calibration / Master Calibration stage1',
  datadir ABCfcs
  LS file
                             = 'FC Ens001 Item001.nc',
  ImplCov npoints
                             = 1
  longindex(1)
                             = 180
  levindex (1)
                             = 25
```

- 2. To plot panels (a), (b), and (c) of Fig. 7, edit the python program  $Plot\_Covs.py$  to set  $plot\_raw\_covs$  to False,  $plot\_implied\_covs$  to True,  $data\_dir\_ImpliedCovs$  to  $Master\_ImpliedCovs$ , longindex to [179], and levindex = [24], and run the python program. Note that the longindex and levindex are longindex(1)-1 and levindex(1)-1 respectively.
- 3. This can be repeated for different experiment configurations to get the rows 2 and 3 of Fig. 7 in the paper.
- 4. Make directory  $Master\_RawCov$  (in the same place as directory  $Master\_Calibration$ ) and enter this directory. Run  $Master\_RawCov.out$  with the following namelist file present (UserOptions.nl). See documentation, §4.7.

```
&UserOptions
 Compute raw covariances
  datadirRawCov
                             = '... / Master_Calibration / Master_Calibration_stage2'
  datadirABCperts
  Nens
  NensMems
                             = 1
                             = 260
  Nlats
  ImplCov npoints
                             = 1
  longindex(1)
                             = 180
  levindex (1)
                             = 25
```

5. To plot panels (j), (k), and (l) of Fig. 7, edit the python program  $Plot\_Covs.py$  to set  $plot\_raw\_covs$  to True,  $plot\_implied\_covs$  to False,  $data\_dir\_RawCovs$  to  $Master\_RawCovs$ , Nens to 1, NEnsMems to 260, longindex to [179], and levindex = [24], and run the python program. Note that the longindex and levindex are longindex(1)-1 and levindex(1)-1 respectively.

### 8 Figure 8

This is a schema, and so doesn't require production of any results.

### 9 Figure 9

- 1. Make an ABC-style initial state (in order to generate synthetic observations and to measure errors from). Make a directory *Master\_PrepareABC\_InitState* (in the same place as directory *Master\_Calibration*) and enter this directory.
- 2. Run Master\_PrepareABC\_InitState.out with the following namelist file present (UserOptions.nl). See documentation, §4.1.

```
&UserOptions
! Master_PrepareABC_InitState
  Init ABC opt
  datadirUM
                             = '/home/data/UMdir'
  init um file
                             = 'Member0001 . nc'
  datadirABC out
  init ABC file
                             = 'ABC InitialConds.nc'
  latitude
  Regular_vert_grid
                             = .TRUE.
  Adv tracer
                             = .TRUE.
  gravity_wave_switch
                             = . FALSE.
  f
                             = 1.0E-4
  A
                             = 0.02
  В
                             = 0.01
  C
                             = 1.0 E4
  BoundSpread
                             = 100.
  press_source_x
                             = 200
                             = 6
  press_source_z
                             = 0.005
  {\tt press\_amp}
                             = 120
  x_scale
                             = 14
  z_scale
```

3. Make a short forecast from this initial state to spin-up characteristics of the ABC model. Make a directory *Master RunNLModel* (in the same place as directory *Master Calibration*) and enter this directory.

4. Run Master\_RunNLModel.out with the following namelist file present (UserOptions.nl). See documentation, §4.2.

```
&UserOptions
  Running ABC model
  datadirABC in
                             = '../ Master PrepareABC InitState'
  init ABC file
                             = 'ABC InitialConds.nc'
  datadirABC out
  output\_ABC\_file
                             = 'Truth.nc'
                             = 'ABC Diagnostics.dat'
  diagnostics_file
                             = 7200.0
  runlength
  ndumps
                              = 4.0
  Lengthscale diagnostics
                             = . FALSE.
                              = 0.02
  В
                              = 0.01
  \mathbf{C}
                              = 1.0 E4
  Adv tracer
                              = .TRUE.
```

- 5. Specify the observation network. Make directory  $Master\_MakeBgObs\_ObsNetwork$  (in the same place as directory  $Master\_Calibration$ ) and enter this directory.
- 6. Run Master\_MakeBgObs.out with the following namelist file present (UserOptions.nl). See documentation, §4.8.

```
&UserOptions
! Specification of observation network
  Generate mode
                             = 1
  ObsSpec%year 0
                             = 2010
  ObsSpec%month0
                             = 1
  ObsSpec%day0
                             = 1
  ObsSpec%hour0
                             = 0
  ObsSpec%min0
                             = 0
  ObsSpec%sec0
                             = 0
  ObsSpec%NumBatches
                             = 7
  datadir_ObsSpec
                             = \ \ 'ObsSpec.dat'
  ObsSpec_file
  ObsSpec%batch(1)
                             = 1
  ObsSpec%seconds (1)
                             = 0
  ObsSpec%ob of what (1)
                             = 4
                                        ! rp
  ObsSpec%NumObs long(1)
                             = 18
  ObsSpec\%NumObs height(1) = 20
  ObsSpec\%long_min(1)
                             = 10.0
  ObsSpec\%long\_max(1)
                             = 530000.0
  ObsSpec%height min(1)
                             = 1.0
  ObsSpec%height max(1)
                             = 12000.0
  ObsSpec%stddev(1)
                             = 0.0015
  ObsSpec%batch(2)
                             = 2
  ObsSpec%seconds (2)
                             = 600
  ObsSpec%ob of what (2)
                             = 4
                                        ! rp
  ObsSpec%NumObs_long(2)
                             = 18
  ObsSpec\%NumObs\_height(2) = 20
  ObsSpec\%long min (2)
                             = 10.0
  ObsSpec\%long_max(2)
                             = 530000.0
  ObsSpec\%height\_min(2)
                             = 1.0
```

```
ObsSpec%height max(2)
                           = 12000.0
ObsSpec%stddev(2)
                           = 0.0015
ObsSpec%batch(3)
                           = 3
                           = 1200
ObsSpec\%seconds(3)
                                      ! rp
ObsSpec%ob of what (3)
                           = 4
ObsSpec\%NumObs\_long(3)
                           = 18
ObsSpec\%NumObs height(3) = 20
ObsSpec%long min(3)
                           = 10.0
ObsSpec%long max(3)
                           = 530000.0
ObsSpec%height min(3)
                           = 1.0
ObsSpec%height max(3)
                           = 12000.0
ObsSpec%stddev(3)
                             0.0015
ObsSpec%batch(4)
                           = 4
ObsSpec%seconds (4)
                           = 1800
ObsSpec%ob of what (4)
                           = 4
                                      ! rp
ObsSpec%NumObs long(4)
                           = 18
ObsSpec\%NumObs\_height(4) = 20
ObsSpec%long min(4)
                           = 10.0
ObsSpec\%long max (4)
                           = 530000.0
ObsSpec%height min(4)
                           = 1.0
ObsSpec%height max (4)
                           = 12000.0
ObsSpec%stddev(4)
                           = 0.0015
ObsSpec%batch(5)
                           = 5
ObsSpec%seconds (5)
                           = 2400
ObsSpec%ob of what (5)
                           = 4
                                      ! rp
ObsSpec%NumObs long(5)
                           = 18
ObsSpec%NumObs height (5)
                           = 20
ObsSpec%long min(5)
                           = 10.0
ObsSpec%long max(5)
                           = 530000.0
ObsSpec%height min(5)
                           = 1.0
                           = 12000.0
ObsSpec%height max (5)
ObsSpec%stddev(5)
                           = 0.0015
ObsSpec%batch (6)
                           = 6
ObsSpec%seconds (6)
                           = 3000
ObsSpec\%ob\_of\_what(6)
                           = 4
                                      ! rp
ObsSpec%NumObs long(6)
                           = 18
ObsSpec\%NumObs height(6) = 20
ObsSpec%long min(6)
                           = 10.0
ObsSpec%long max(6)
                           = 530000.0
ObsSpec%height_min(6)
                           = 1.0
ObsSpec%height max(6)
                             12000.0
ObsSpec%stddev(6)
                           = 0.0015
ObsSpec%batch (7)
ObsSpec%seconds (7)
                           = 3600
ObsSpec%ob of what (7)
                           = 4
                                      ! rp
ObsSpec%NumObs long(7)
                           = 18
ObsSpec%NumObs height (7)
                             20
ObsSpec%long min(7)
                           = 10.0
ObsSpec%long max(7)
                           = 530000.0
ObsSpec%height min(7)
                           = 1.0
ObsSpec%height max (7)
                           = 12000.0
ObsSpec%stddev(7)
                           = 0.0015
```

7. Now run the cycled data assimilation. Make directory  $CycledDA\_obs\_rp$  (in the same place as directory  $Master\ Calibration$ ) and enter this directory.

- 8. Copy the bash script DAcycle001.sh to this directory and set EXPERIMENT to  $CycledDA\_obs\_rp$ ,  $BASE\_DIR$  to the full path to the parent of this directory appended with /\$EXPERIMENT,  $N\_CYCLES$  to 30,  $N\_OUTER\_LOOPS$  to 1,  $N\_INNER\_LOOPS\_MAX$  to 100,  $DA\_WINDOW$  to 3600.0,  $DA\_WINDOW\_INT$  to 3600,  $OBS\_NETWORK\_DIR$  to  $\$BASE\_DIR/.../Master\_MakeBgObs\_ObsNetwork$ ,  $INITIAL\_TRUTH\_DIR$  to  $\$BASE\_DIR/Master\_RunNLModel$ ,  $CVT\_DIR$  to  $\$BASE\_DIR/.../MasterCalibration$ ,  $CODE\_DIR$  to the directory containing the main fortran code,  $PLOT\_CODE\_DIR$  to the directory containing the python plotting code,  $BACKGROUND\_ALREADY\_COMPUTED$  to 0, A to 0.02, B to 0.01, C to 1.0E4, and PLOT to 1.
- 9. Run the back script DAcycle001.sh.
- 10. The cost function diagnostics of Fig. 9 should appear inside  $\$BASE \ DIR/CycledDA \ obs \ rp/da \ cycle \ 0007/Plots$ .

## 10 Figure 10

The panels of Fig. 10 should also appear inside  $BASE\_DIR/CycledDA\_obs\_rp/da\_cycle\_0007/Plots$ . as per instructions for Fig. 9.

## 11 Figure 11

Much of the data shown in Fig. 11 should appear inside \$BASE\_DIR/CycledDA\_obs\_rp/Plots as per instructions for Fig. 9. The specific panels of Fig. 11 are made by editing PlotMultiCycleErrors4paper.py.

### 12 Figures 12 and 13

The above steps can be repeated for different options – in particular  $CVT\%CVT\_param\_opt\_gb$  can be set to 3 to turn-off the geostrophic balance constraint in the CVT, and  $CVT\%CVT\_param\_opt\_reg$  can be set to 2 to turn-off the vertical regression step that accompanies the geostrophic balance.