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Supporting Information for

The Impact of the Extreme 2015-16 El Niño on the Mass Balance of the Antarctic Ice Sheet

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Additional Supporting Information (Files uploaded separately)

Introduction

Figures S1-S2 compare the GRACE mass anomaly estimates per region (S1) and drainage basin (S2) using the Coastal Resolution Improvement Filter (CRI) version from JPL; and the two non-CRI versions, one without consideration for the influence of ocean mass on mascons, and one where ocean mass is redistributed (i.e. the M_T timeseries in the main manuscript; see Chapter 2.1). Figure S3 enclosed in this document shows the pre- and post-El Niño anomalies for MSLP and TP for the 1997-98 El Niño. The processing used to produce the figure is as described in Section 2.2 of the paper, but for the period November 1996-October 1997 (pre-El Niño) and November 1997-October 1998 (post-El Niño). Table S1 provides the mass anomaly estimates for each region and basin for the period February 2012-May 2015 (pre-Niño) and June 2015-February 2017 (post-Niño). Finally, this file also contains additional information for the Datasets and Methods (Chapter 2) regarding the processing of the uncertainties for the GRACE Mascons (Chapter 2.1) and the Meteorological Fields (Chapter 2.2) timeseries.

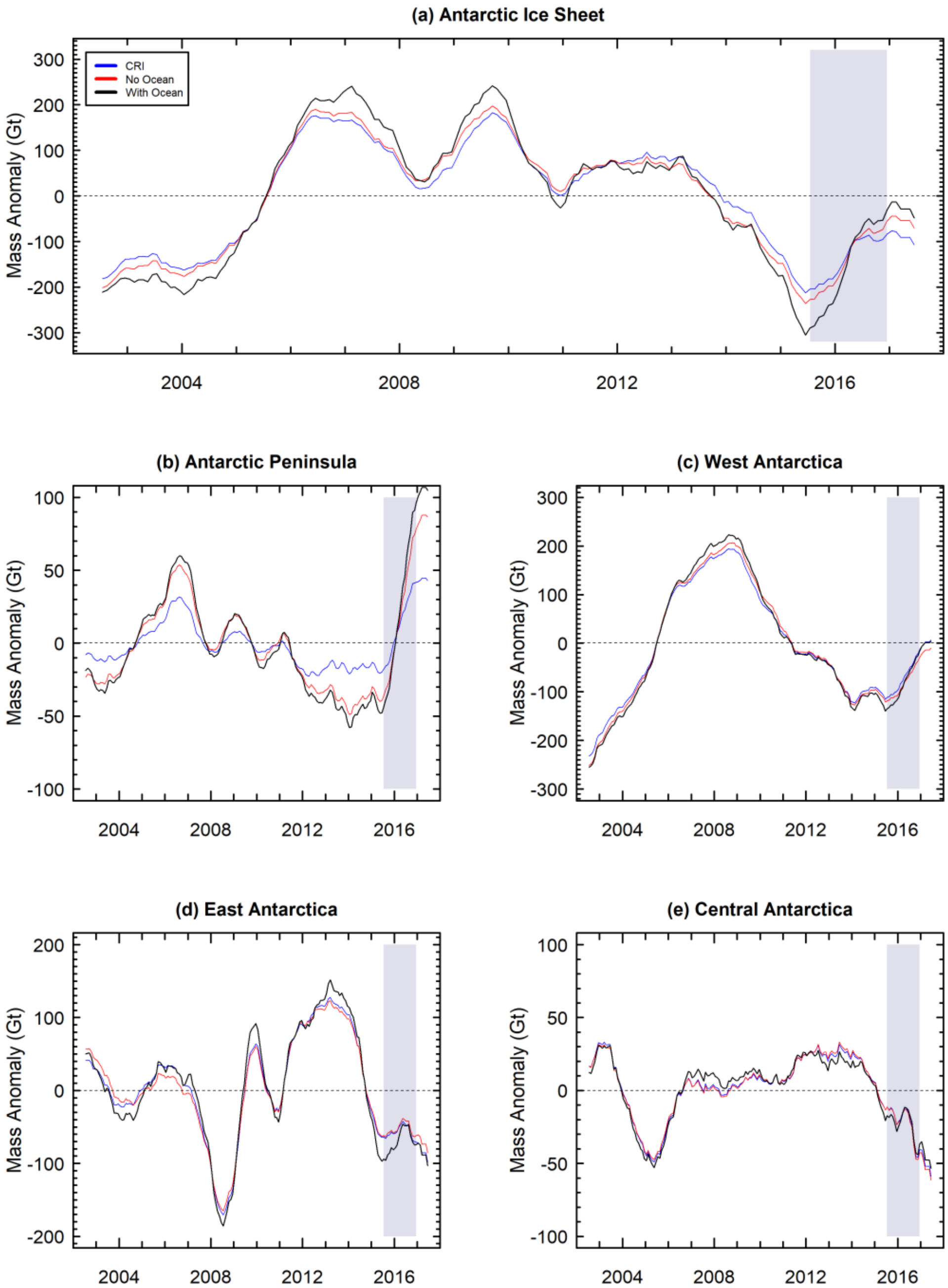

Figure S1. *Individual steps used to obtain interannual variations in total mass from GRACE for: (a) Antarctic Ice Sheet, (b) Antarctic Peninsula, (c) West Antarctica, (d) East Antarctica, (e) Central Antarctica. Each timeseries corresponds to: (blue) version of the JPL dataset containing a Coastal Resolution Improvement (CRI) filter to improve separation of land and ocean boundaries; (red) the non-CRI version of the dataset but with no redistribution of ocean mass in respect to their respective basins; and (black) the non-CRI version used in the manuscript where mascons sharing both land and ocean portions are redistributed to other basins over* *which they lie (see Chapter 2.1). The blue-shaded box represents the El Niño period July 2015 to December 2016.*

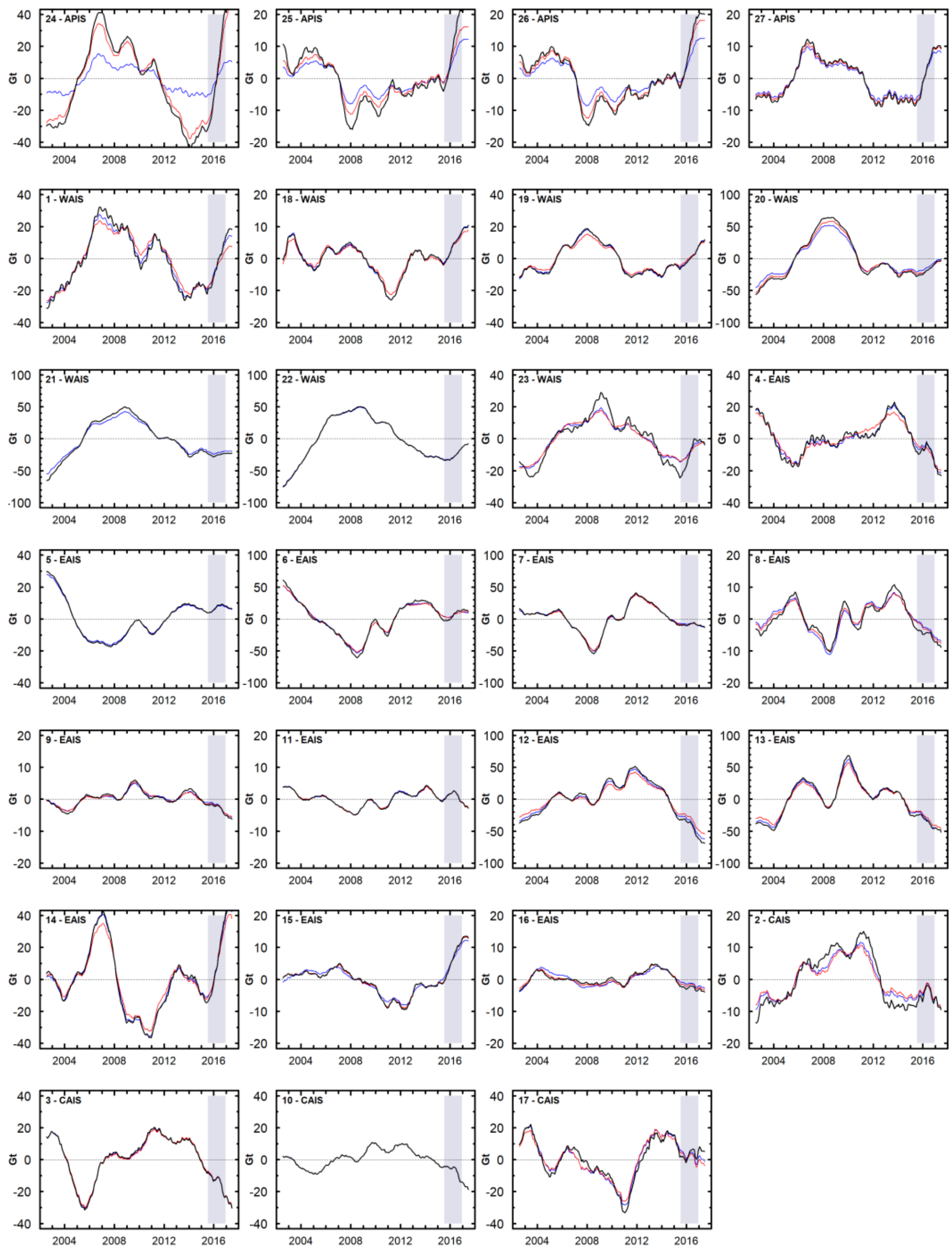

Figure S2. *Individual steps used to obtain interannual variations in total mass from GRACE for each of the individual drainage basins defined by Zwally et al. (2012). Each timeseries corresponds to: (blue) version of the JPL dataset containing a Coastal Resolution Improvement (CRI) filter to improve separation of land and ocean boundaries; (red) the non-CRI version of the dataset but with no redistribution of ocean mass in respect* *to their respective basins; and (black) the non-CRI version used in the manuscript where mascons sharing both land and ocean portions are redistributed to other basins over which they lie (see Chapter 2.1). The blue-shaded box represents the El Niño period July 2015 to December 2016.*

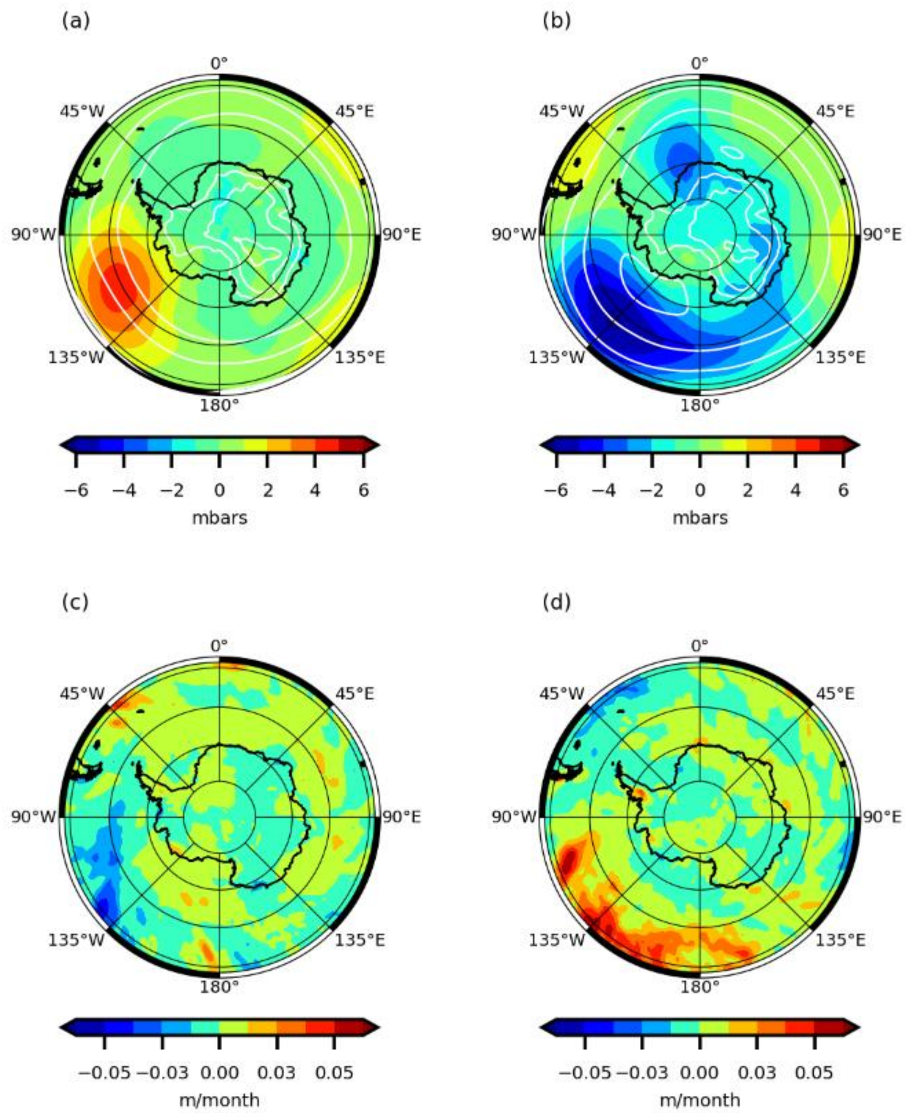

Figure S3. *Pre (Nov. 1996–Oct. 1997) and post (Nov. 1997–Oct. 1998) peak El Niño yearly means of mean sea level pressure (MSLP) and total precipitation (TP) from ERA-interim: (a) MSLP pre-El Niño, (b) MSLP post-El Niño, (c) TP pre-El Niño, (d) TP post-El Niño.*

Region/basin	Skill (%)	M_T (Gt)		M_P (Gt)	
		Pre-Niño	Post-Niño	Pre-Niño	Post-Niño
		02/12–05/15	06/15–03/17	02/12–05/15	06/15–03/17
AIS	79	-341±33	277±91	-260±36	210±59
APIS	60	16±17	155±44	-19±8	69±18
24	79	-21±8	87±18	-14±6	52±14
25	59	2±3	27±7	-4±4	13±9
26	16	4±4	23±8	-3±4	0±6
27	10	-1±4	18±9	2±3	3±4
WAIS	85	-106±17	141±50	-45±16	152±26
1	87	-25±33	41±91	-16±8	33±16
18	5	5±16	12±50	0±3	10±5
19	89	4±25	17±63	4±5	15±5
20	84	-11±18	24±44	3±8	29±13
21	64	-22±25	0±67	1±4	12±7
22	76	-30±28	24±70	-16±7	32±11
23	81	-22±8	23±20	-21±5	21±7
EAIS (overall)	91	-219±64	-18±158	-196±31	10±49
EAIS (coastal)	93	-177±14	-9±34	-181±29	11±45
4	70	-8±17	-14±44	-17±5	-17±8
5	98	5±14	3±34	7±2	4±3
6	97	-16±45	16±105	-13±5	10±7
7	96	-46±43	-1±99	-45±12	5±6
8	48	-6±15	-5±32	0±1	-8±3
9	43	-1±10	10±20	-2±2	-9±4
11	91	-3±14	-2±29	-3±2	-2±3
12	96	-78±49	-35±96	-66±15	-29±24
13	90	-28±80	-23±170	-40±16	-14±31
14	92	-1±45	62±84	-7±12	52±14
15	71	8±8	15±18	4±3	20±8
16	<0	-3±13	-1±26	1±2	-1±3
CAIS	61	-41±45	-27±105	-15±11	-21±21
2	31	-15±17	0±50	-1±3	1±4
3	90	-22±64	-19±158	-16±6	-23±11
10	86	-15±43	-12±85	-13±4	-11±6
17	70	11±63	4±142	14±8	12±16

Table S1. *Table of mass change per region and drainage basin in gigatons for pre- and post-Niño conditions for the Antarctic Ice Sheet. Skill represents the percentage of variance in M_T that is accounted for by the M_P timeseries. Abbreviations are as follows: AIS: Antarctic Ice sheet; APIS: Antarctic Peninsula Ice Sheet; WAIS: West Antarctic Ice Sheet; EAIS: East Antarctic Ice Sheet (overall); EAIS (coastal): East Antarctic Ice Sheet coastal basins (termed: EAIS in Figure 1 and S1); CAIS: Central Antarctic Ice Sheet.*

Additional Information:

2. Datasets and Methods

2.1. GRACE Mascons: Uncertainty Estimates

To provide error bounds for the basin-scale timeseries, the gridded one-sigma uncertainties supplied with the GRACE mascons were integrated over each basin, multiplied by two, and added and subtracted from the basins mass timeseries to give 95% confidence intervals. This assumes that the errors are correlated over the basin and therefore gives the most pessimistic uncertainty estimate. These basin-scale errors were then summed in quadrature to obtain the regional-scale errors.

As the errors are derived directly from the formal errors supplied with the mascons, the growth in the M_T errors at the end of the record most likely reflects the degradation in the quality of the solutions as the mission was nearing its end and fewer observations were used in forming each monthly solution. Similarly, at the beginning of the record there were fewer observations as the satellites were still being calibrated.

2.2. Meteorological Field: Uncertainty Estimates

Clearly, with only five estimates, which are not entirely independent, given the ERA products' shared heritage and the fact that the MAR and RACMO2 models are forced with

ERA fields, it is not possible to provide a truly robust estimate of the uncertainty for M_P. Nonetheless, we provide some measure of uncertainty (or at least spread) by computing 2-sigma confidence intervals according to $2\sigma = \pm A \cdot S/\sqrt{5}$, where S is the sample standard deviation and $A = t_{(0.05,4)}$ = 2.13 is the appropriate Student's t-distribution parameter. As before, regional-scale confidence intervals are obtained by summing the basin-scale estimates in quadrature.