

Supporting Information for

**The Global Patterns of Interannual and Intraseasonal Mass Variations in the Oceans
from GRACE and GRACE Follow-On Records**

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Introduction

Table S1 shows the GRACE(-FO) time steps used for the analysis reported in the main manuscript. In the original dataset, the time steps are expressed in days after 01/01/2002. Table S1 expresses the dates converted into *MM-dd hh:mm* format. Some time-steps do not point to the middle of the month. They highlight months for which days have been asymmetrically discarded during processing (see https://grace.jpl.nasa.gov/data/grace_months/). For the analysis, days with a time lag of more than 5 days have been ignored (gray in table S1). Out of the initial 190, we, therefore, considered 175 time-steps.

Table S2 shows the complete list of climate indices, with download links, that were correlated to the temporal patterns of the GRACE(-FO) patterns. All data were acquired from <https://psl.noaa.gov/data/climateindices/list/>, which also provides a brief description and the appropriate references for the indices.

Figure S1 shows the 23 spatial patterns of the PCA-Varimax retrieved modes.

Figure S2 shows the 23 temporal patterns of the PCA-Varimax retrieved modes.

Figures S3 to 6 show the spatial pattern of Pearson's correlation between PCA-Varimax GRACE(-FO) temporal pattern (Fig. S2) and Sea-Level Anomaly (SLA), Wind Stress Curl (WSC), zonal wind stress (τ_x), and meridional wind stress (τ_y).

Figure S7 presents the correlation analysis results, same as Figure 3 in the main manuscript, however, for the full list of climate indices reported in Table S2.

Month Year	1	2	3	4	5	6	7	8	9	10	11	12
2002				0 04-17 12:00	1 05-10 12:00			2 08-16 12:00	3 09-16 00:00	4 10-16 12:00	5 11-16 00:00	6 12-16 12:00
2003	7 01-16 12:00	8 02-15 00:00	9 03-16 12:00	10 04-16 00:00	11 05-11 12:00		12 07-16 12:00	13 08-16 12:00	14 09-16 00:00	15 10-16 00:00	16 11-16 00:00	17 12-16 12:00
2004	18 01-07 12:00	19 02-17 00:00	20 03-16 12:00	21 04-16 00:00	22 05-16 12:00	23 06-16 00:00	24 07-16 12:00	25 08-16 12:00	26 09-16 00:00	27 10-16 12:00	28 11-16 00:00	29 12-16 12:00
2005	30 01-16 12:00	31 02-15 00:00	32 03-16 12:00	33 04-16 00:00	34 05-16 12:00	35 06-16 00:00	36 07-16 12:00	37 08-16 12:00	38 09-16 00:00	39 10-16 12:00	40 11-16 00:00	41 12-16 12:00
2006	42 01-16 12:00	43 02-15 00:00	44 03-16 12:00	45 04-16 00:00	46 05-16 12:00	47 06-16 00:00	48 07-16 12:00	49 08-16 12:00	50 09-16 00:00	51 10-16 12:00	52 11-16 00:00	53 12-16 12:00
2007	54 01-16 12:00	55 02-15 00:00	56 03-16 12:00	57 04-16 00:00	58 05-16 12:00	59 06-16 00:00	60 07-16 12:00	61 08-16 12:00	62 09-16 00:00	63 10-16 12:00	64 11-16 00:00	65 12-16 12:00
2008	66 01-16 12:00	67 02-15 12:00	68 03-16 12:00	69 04-16 00:00	70 05-16 12:00	71 06-16 00:00	72 07-16 12:00	73 08-16 12:00	74 09-16 00:00	75 10-16 12:00	76 11-16 00:00	77 12-16 12:00
2009	78 01-16 12:00	79 02-15 00:00	80 03-16 12:00	81 04-16 00:00	82 05-16 12:00	83 06-16 00:00	84 07-16 12:00	85 08-16 12:00	86 09-16 00:00	87 10-16 12:00	88 11-16 00:00	89 12-16 12:00
2010	90 01-16 12:00	91 02-15 00:00	92 03-16 12:00	93 04-16 00:00	94 05-16 12:00	95 06-16 00:00	96 07-16 12:00	97 08-16 12:00	98 09-16 00:00	99 10-16 12:00	100 11-16 00:00	101 12-14 12:00
2011		102 02-18 12:00	103 03-16 12:00	104 04-16 00:00	105 05-16 12:00		106 07-18 12:00	107 08-16 12:00	108 09-16 00:00	109 10-16 12:00	110 11-01 12:00	
2012	111 01-01 00:00	113 02-15 12:00	114 03-16 12:00	115 04-04 12:00		116 06-16 00:00	117 07-16 12:00	118 08-16 12:00	119 09-13 00:00		120 11-18 12:00	121 12-16 12:00
	112 01-16 12:00											
2013	122 01-16 12:00	123 02-14 00:00		124 04-21 00:00	125 05-16 12:00	126 06-16 00:00	127 07-16 12:00			128 10-16 12:00	129 11-16 00:00	130 12-16 12:00
2014	131 01-09 12:00		132 03-16 12:00	133 04-16 00:00	134 05-16 12:00	135 06-13 00:00		136 08-16 12:00	137 09-16 00:00	138 10-16 12:00	139 11-17 00:00	
2015	140 01-22 12:00	141 02-15 00:00	142 03-16 12:00	143 04-16 00:00			145 07-15 12:00	146 08-16 12:00	147 09-14 12:00			148 12-23 12:00
				144 04-27 00:00								
2016	149 01-16 12:00	150 02-14 00:00	151 03-16 12:00		152 05-20 00:00	153 06-16 00:00	154 07-15 12:00	155 08-21 12:00			156 11-27 12:00	157 12-24 12:00
2017	158 01-21 00:00		159 03-31 12:00	160 04-24 12:00	161 05-12 12:00	162 06-11 00:00						
2018					GRACE FO	163 06-16 00:00	164 07-10 00:00			165 10-31 12:00	166 11-16 00:00	167 12-16 12:00
2019	168 01-16 12:00	169 02-14 00:00	170 03-16 12:00	171 04-16 00:00	172 05-16 12:00	173 06-16 00:00	174 07-16 12:00	175 08-16 12:00	176 09-16 00:00	177 10-16 12:00	178 11-16 00:00	179 12-16 12:00
2020	180 01-16 12:00	181 02-15 12:00	182 03-16 12:00	183 04-16 00:00	184 05-16 12:00	185 06-16 00:00	186 07-16 12:00	187 08-16 12:00	188 09-16 00:00	189 10-16 12:00		

Table S1. GRACE time indices: 190 Time stamps in TELLUS_GRAC-GRFO_MASCON_CRI_GRID_RL06_V2 (ix MM-dd hh:mm). Missing values are left blank. Dropped time-stamps are in gray.

Abbrev.	Name	Download Link
aao	Antartic Oscillation	https://psl.noaa.gov/data/correlation/aao.data
ammsst	Atlantic Meridional Mode (SST)	https://psl.noaa.gov/data/timeseries/monthly/AMM/ammsst.data
ammwind	Atlantic Meridional Mode (wind)	https://psl.noaa.gov/data/timeseries/monthly/AMM/ammwind.data
amonsm	Smoothed Atlantic Multidecadal Oscillation	https://psl.noaa.gov/data/correlation/amon.sm.data
amonus	Unsmoothed Atlantic Multidecadal Oscillation	https://psl.noaa.gov/data/correlation/amon.us.data
ao	Arctic Oscillation	https://psl.noaa.gov/data/correlation/ao.data
atltri	Atlantic Tripole SST EOF	https://psl.noaa.gov/data/correlation/atltri.data
CAR_ersst	Caribbean Index (CAR)	https://psl.noaa.gov/data/correlation/CAR_ersst.data
censo	Bivariate ENSO Timeseries	https://psl.noaa.gov/data/correlation/censo.data
dmi	Dipole Mode Index	https://psl.noaa.gov/gcos_wgsp/Timeseries/Data/dmi.had.long.data
dmieast	Dipole Mode Index (East)	https://psl.noaa.gov/gcos_wgsp/Timeseries/Data/dmiwest.had.long.data
dmiwest	Dipole Mode Index (West)	https://psl.noaa.gov/gcos_wgsp/Timeseries/Data/dmieast.had.long.data
ea	Eastern Asia/Western Russia	https://psl.noaa.gov/data/correlation/ea.data
eofpac	Tropical Pacific SST EOF	https://psl.noaa.gov/data/correlation/eofpac.data
epo	East Pacific/North Pacific Oscillation	https://psl.noaa.gov/data/correlation/epo.data
espi	ENSO precipitation index	https://psl.noaa.gov/data/correlation/espi.data
glaam	Globally Integrated Angular Momentum	https://psl.noaa.gov/data/correlation/glaam.data.scaled
gmsst	Global Mean Lan/Ocean Temperature Index	https://psl.noaa.gov/data/correlation/gmsst.data
ipotpi	Tripole Index for the Interdecadal Pacific Oscillation	https://psl.noaa.gov/data/timeseries/IPOTPI/ipotpi.hadisst2.data
meiv2	Multivariate ENSO Index Version 2	https://psl.noaa.gov/enso/mei/data/meiv2.data
nao	North Atlantic Oscillation	https://psl.noaa.gov/data/correlation/nao.data
nina1anom	Extreme Eastern Tropical Pacific SST	https://psl.noaa.gov/data/correlation/nina1.anom.data
nina34anom	East Central Tropical Pacific SST	https://psl.noaa.gov/data/correlation/nina34.anom.data
nina3anom	Eastern Tropical Pacific SST	https://psl.noaa.gov/data/correlation/nina3.anom.data
nina4anom	Central Tropical Pacific SST	https://psl.noaa.gov/data/correlation/nina4.anom.data
noi	Northern Oscillation Index	https://psl.noaa.gov/data/correlation/noi.data
np	North Pacific Pattern	https://psl.noaa.gov/data/correlation/np.data
NTA_ersst	North Tropical Atlantic Index	https://psl.noaa.gov/data/correlation/NTA_ersst.data
oni	Oceanic Niño Index	https://psl.noaa.gov/data/correlation/oni.data
pacwarm	Pacific Warmpool Region	https://psl.noaa.gov/data/correlation/pacwarm.data
pdo	Pacific Decadal Oscillation	https://psl.noaa.gov/data/correlation/pdo.data
pna	Pacific North American Index	https://psl.noaa.gov/data/correlation/pna.data
qbo	Quasi-Biennial Oscillation	https://psl.noaa.gov/data/correlation/qbo.data
sahelrain	Sahel Standardized Rainfall	https://psl.noaa.gov/data/correlation/sahelrain.data
soi	Southern Oscillation Index	https://psl.noaa.gov/data/correlation/soi.data
solar	Solar Flux	https://psl.noaa.gov/data/correlation/solar.data
swmonsoon	SW Monsoon Region rainfall (NM and AZ)	https://psl.noaa.gov/data/correlation/swmonsoon.data
tna	Tropical Northern Atlantic Index	https://psl.noaa.gov/data/correlation/tna.data
tni	Trans-Niño Index	https://psl.noaa.gov/data/correlation/tni.data
tsa	Tropical Southern Atlantic Index	https://psl.noaa.gov/data/correlation/tsa.data
whwp	Western Hemisphere warm pool	https://psl.noaa.gov/data/correlation/whwp.data
wp	Western Pacific Index	https://psl.noaa.gov/data/correlation/wp.data

Table S2. Full list of climate indices and download links

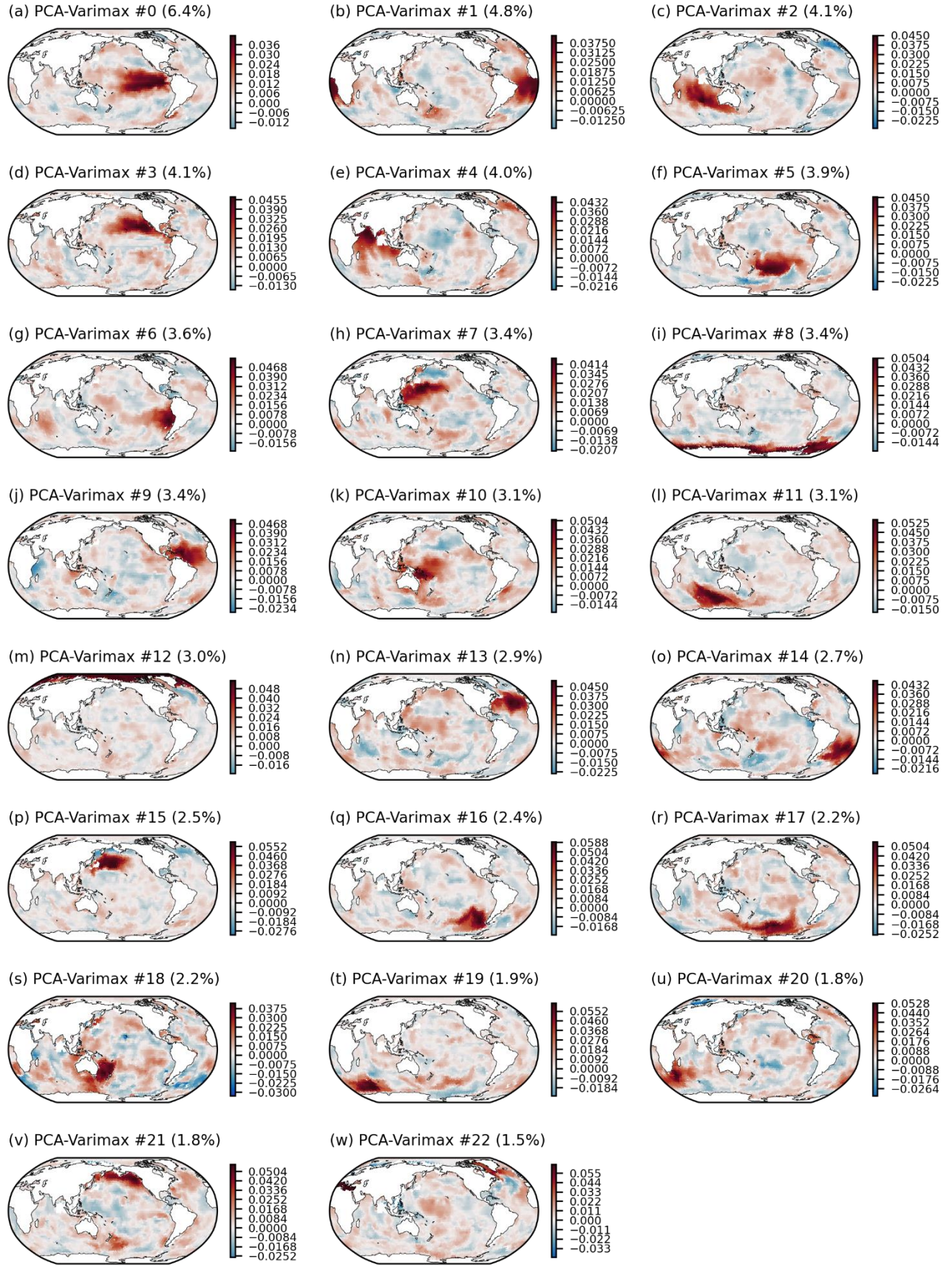


Figure S1. The 23 Spatial PCA-Varimax patterns (a to w) from the decomposition of GRACE(-FO) data.

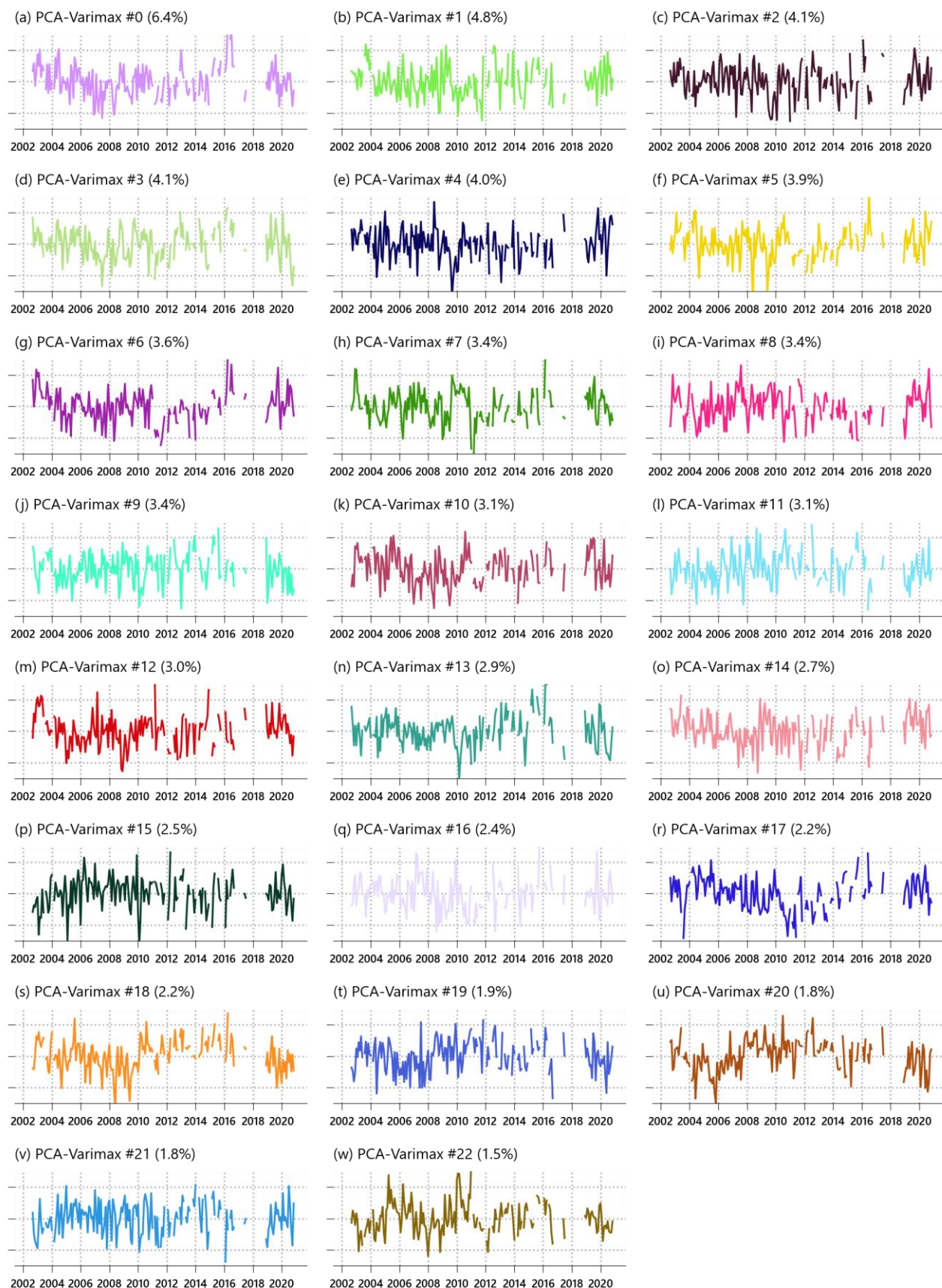


Figure S2. The 23 standardized temporal PCA-Varimax patterns (a to w) from the decomposition of GRACE(-FO) data. Line colors match with the pattern color of Figure 2 in the main manuscript.

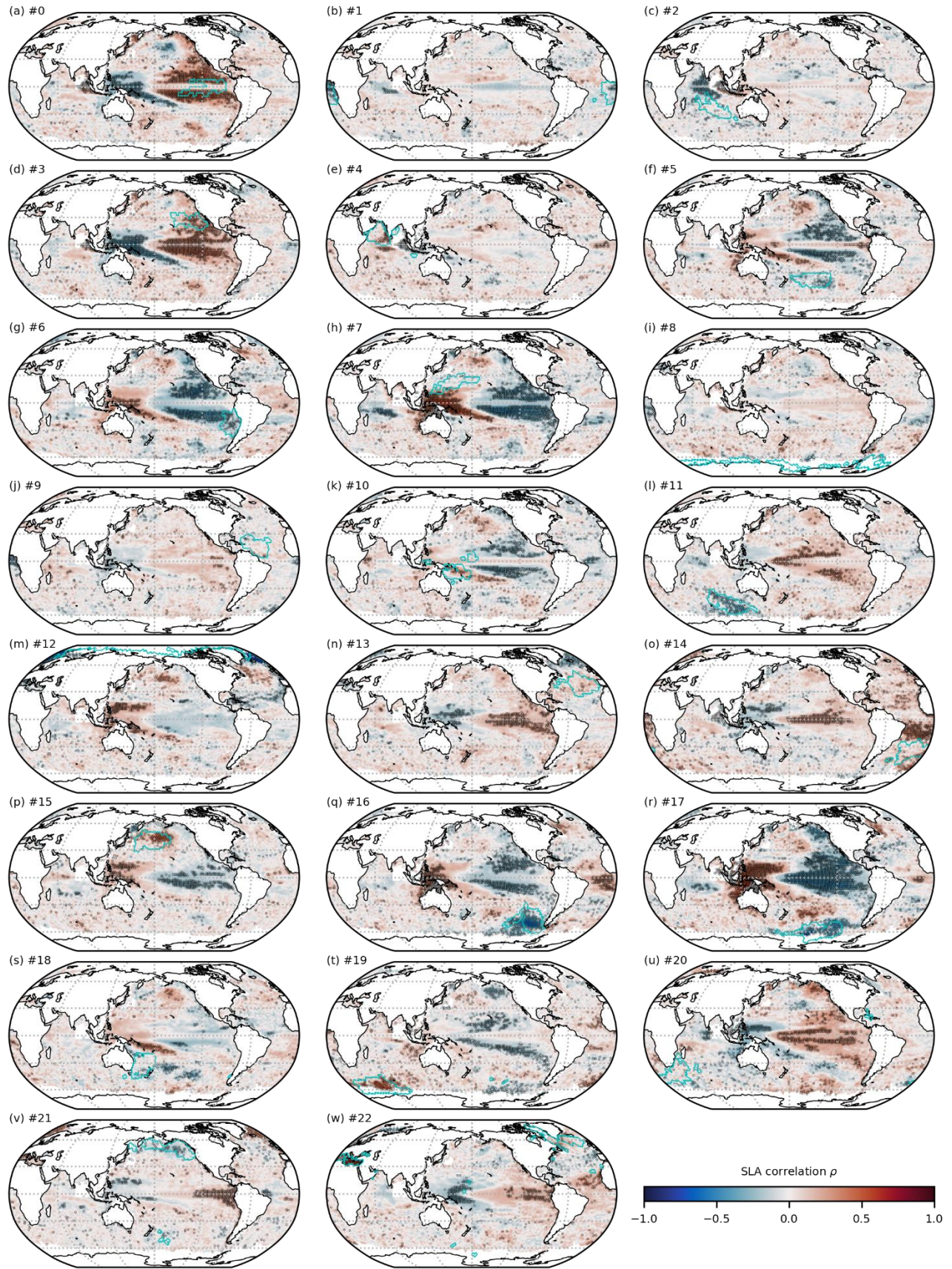


Figure S3. Spatial pattern of Pearson's correlation between PCA-Varimax GRACE(-FO) temporal pattern (Figure S2) and Sea Level Anomaly (SLA). Black dots represent significant correlations based on surrogates of the GRACE(-FO) temporal patterns. The cyan contour is the 98th percentile envelope of the corresponding spatial GRACE(-FO) PCA-Varimax pattern (Figure S1).

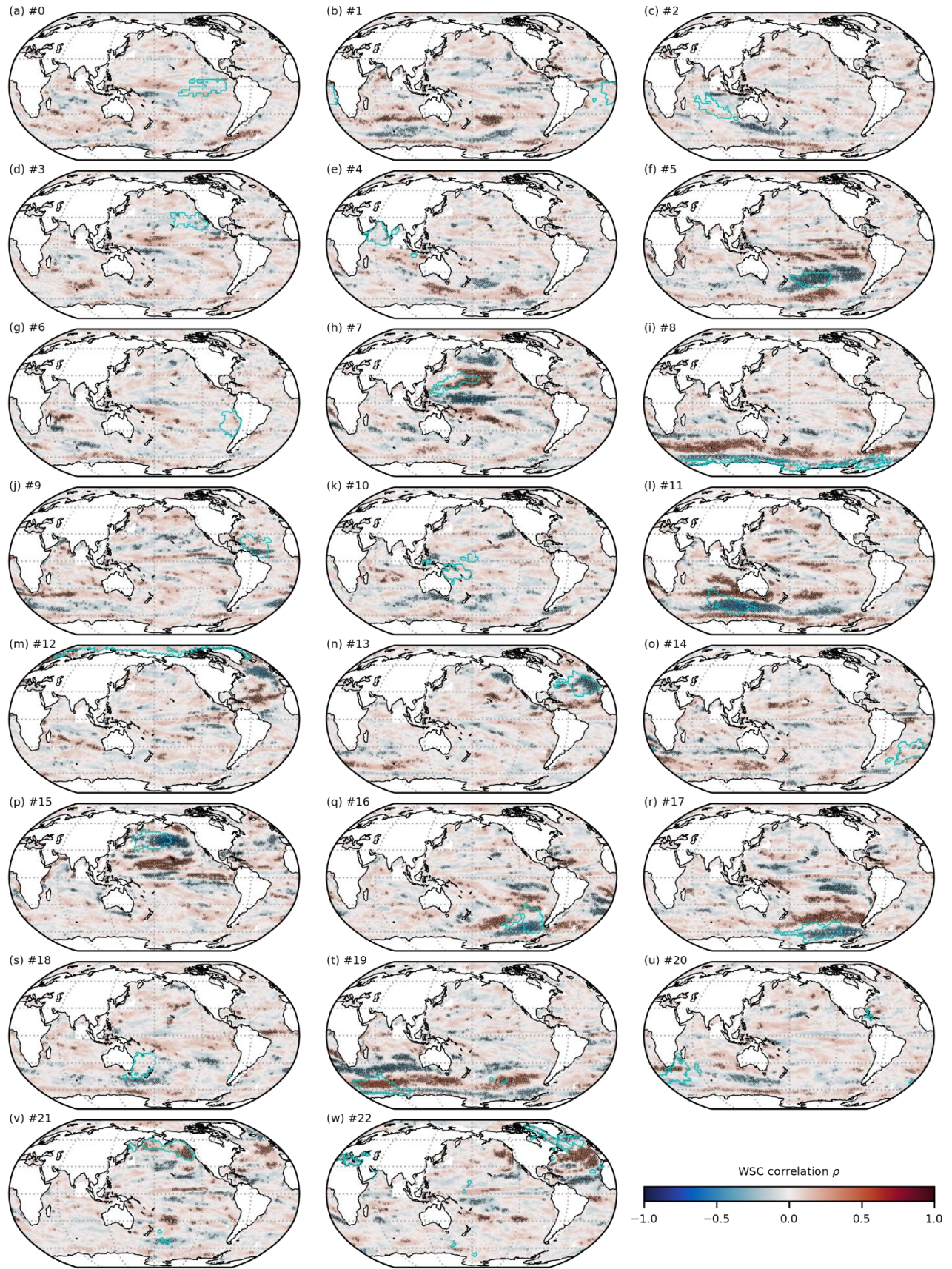


Figure S4. Spatial pattern of Pearson's correlation between PCA-Varimax GRACE(-FO) temporal pattern (Figure S2) and Wind Stress Curl (WSC). Black dots represent significant correlations based on surrogates of the GRACE(-FO) temporal patterns. The cyan contour is the 98th percentile envelope of the corresponding spatial GRACE(-FO) PCA-Varimax pattern (Figure S1).

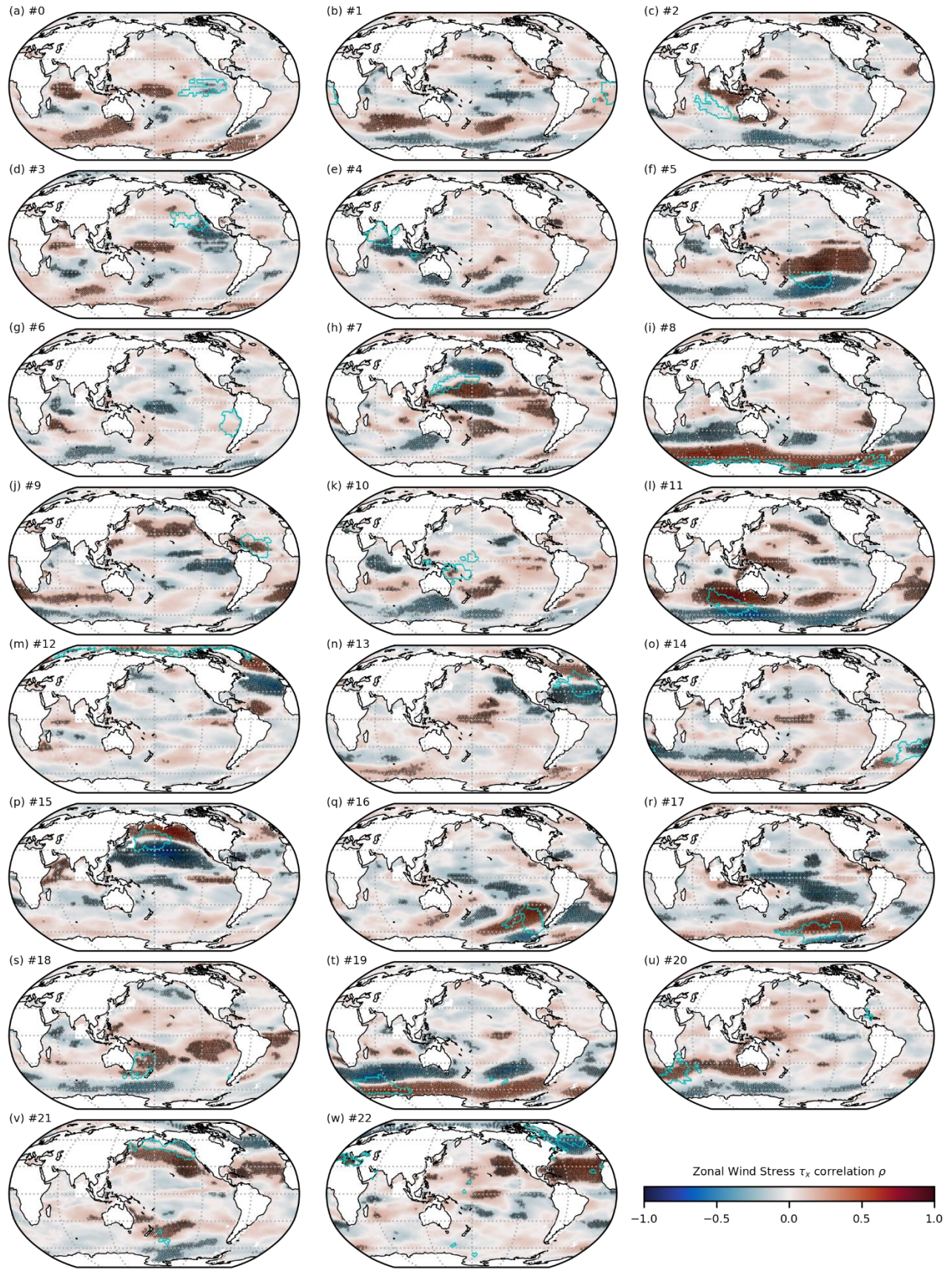


Figure S5. Spatial pattern of Pearson's correlation between PCA-Varimax GRACE(-FO) temporal pattern (Figure S2) and zonal wind stress (τ_x). Black dots represent significant correlations based on surrogates of the GRACE(-FO) temporal patterns. The cyan contour is the 98th percentile envelope of the corresponding spatial GRACE(-FO) PCA-Varimax pattern (Figure S1).

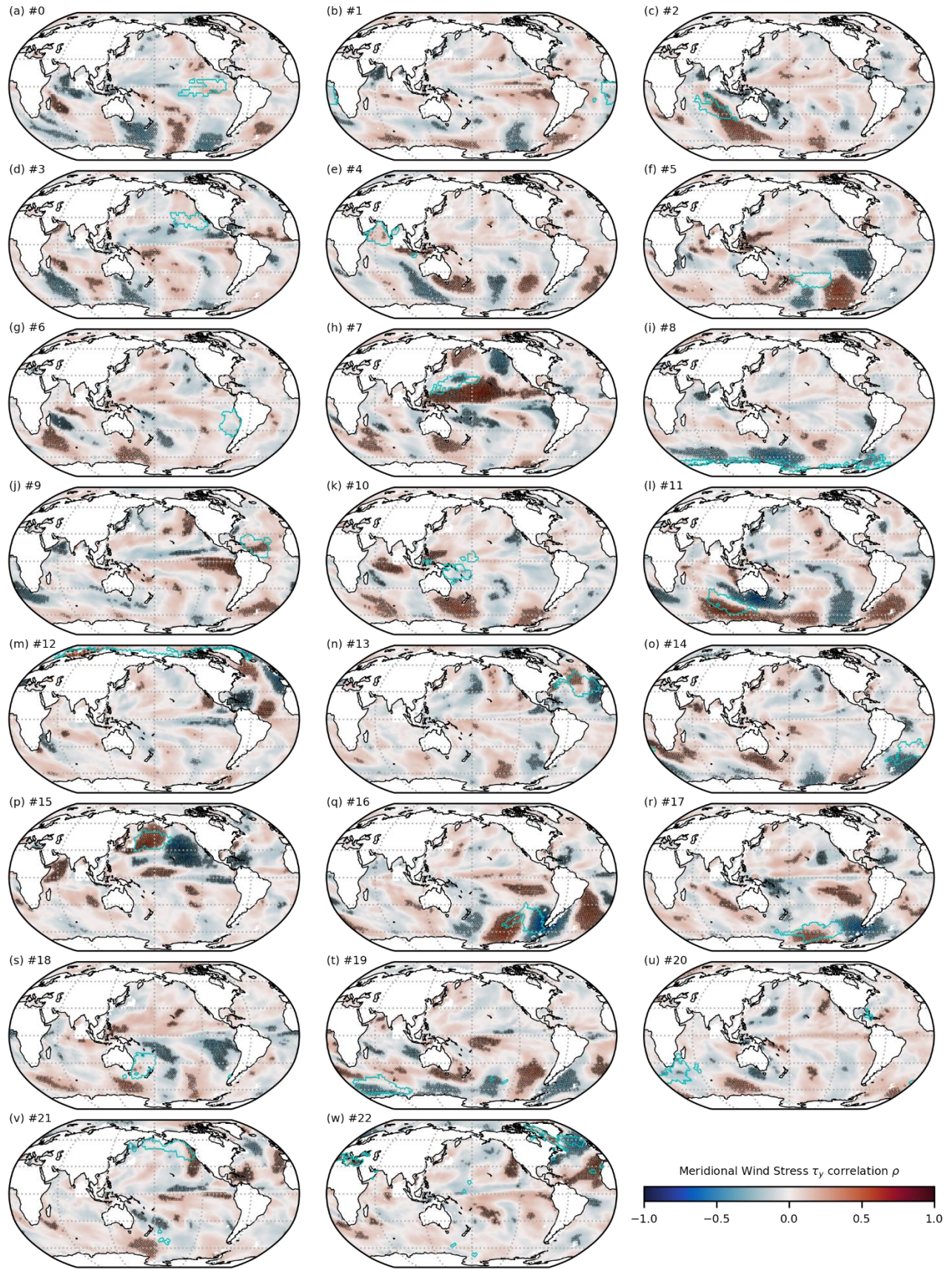


Figure S6. Spatial pattern of Pearson's correlation between PCA-Varimax GRACE(-FO) temporal pattern (Figure S2) and meridional wind stress (τ_y). Black dots represent significant correlations based on surrogates of the GRACE(-FO) temporal patterns. The cyan contour is the 98th percentile envelope of the corresponding spatial GRACE(-FO) PCA-Varimax pattern (Figure S1).

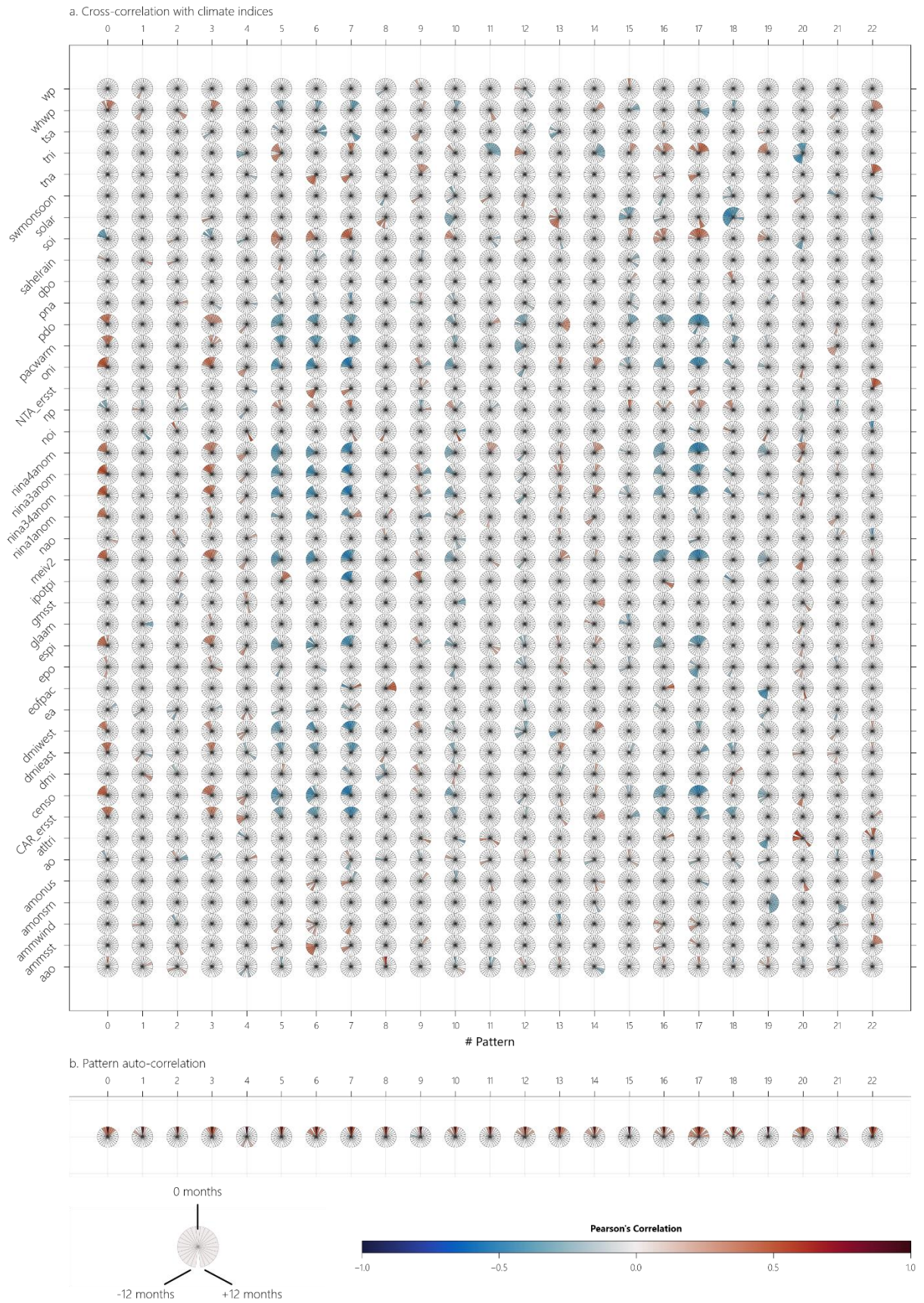


Figure S7. Cross-correlation analysis between the PCA-Varimax GRACE(-FO) patterns and (a) the climate indices of Table S2 and (b) the auto-correlation of the pattern. Same method and display as for Figure 3 in the main manuscript.