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Climate co-variability between South America and Southern Africa at interannual, intraseasonal and synoptic scales

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39 **Abstract**

40 This paper investigates and quantifies co-variability between large-scale convection in the South
41 American and Southern African sectors at different timescales (interannual, intraseasonal and
42 synoptic), during the austral summer seasons (November to February) from 1979 to 2012.
43 Multivariate analyses (Canonical Correlation Analysis and Principal Component Analysis) are
44 applied to daily outgoing longwave radiation (OLR, used as a proxy for atmospheric convection)
45 anomalies to extract the principal modes of variability and co-variability in each and between both
46 regions, filtered to consider the appropriate time-scales. At the interannual timescale, results
47 confirm the predominant role of El Niño Southern Oscillation (ENSO), favoring enhanced
48 convection over both southeastern Brazil and northern Argentina on the one hand, and tropical
49 Africa and the western Indian Ocean on the other hand. At the intraseasonal timescale, the leading
50 mode of co-variability is related to modulations of large-scale atmospheric convection over most
51 of South America, and ten days later, tropical Southern Africa. This mode accounts for the impacts
52 of the Madden-Julian-Oscillation (MJO) over these regions: identifying robust co-variability at the
53 intraseasonal timescale between both regions require thus to consider a temporal shift between the
54 two sectors. At the synoptic scale, however, co-variability consists mostly of a synchronous
55 modulation of the large-scale atmospheric convection over the South American and Southern
56 African sectors. This results from the development of concomitant Rossby waves forming a
57 continuous wave train over the South Atlantic in the mid-latitudes, affecting both the South
58 Atlantic and South Indian Convergence Zones. Among the days when convection shows
59 significant anomalies (30% of the total days in each sector), this synchronous mode occurs about
60 25% of the time, individual Rossby waves modulating convection over one single region only
61 during the remaining 75% events. Another mode of co-variability, involving a single Rossby wave
62 modulating the convection first over the Americas, and four days later over Africa, appears as
63 sensibly weaker than the synchronous mode, suggesting that the “wave train” mode occurs more
64 frequently than the development and propagation of a single wave that could propagate and affect
65 both regions.

66

67 **Key-words**

68 El Niño Southern Oscillation; Madden-Julian Oscillation; Rossby waves; Co-variability;
69 Atmospheric convection; South Atlantic Convergence Zone; South Indian Convergence Zone.

70 *This study is dedicated to the memory of Professor Gérard Beltrando.*

71

72

73 **1. Introduction**

74

75 Three main convergence zones (CZ) linking the tropics to the mid-latitudes are found in the
76 Southern Hemisphere (Streten 1973): the South Pacific (SPCZ, northeast of Australia: Vincent
77 1994), South Atlantic (SACZ, spreading from the Amazonia basin to the southwestern Atlantic
78 Ocean: Liebmann et al. 1999; Carvalho et al. 2004) and South Indian (SICZ, from Southern Africa
79 to the southwest Indian Ocean: Cook 2000) convergence zones. These CZs are associated with
80 significant rainfall, notably during the Southern Hemisphere summer and therefore their variability
81 in space and time (i.e. position, intensity) contribute to modulate large-scale rainfall over their
82 corresponding regions, affecting the livelihoods of millions of people.

83 As a consequence, many studies have been devoted to improve our understanding of the physical
84 mechanisms responsible for their establishment, and what controls their variability at time-scales
85 ranging mostly from synoptic to interannual. Early studies by Kodama (1992; 1993) suggested that
86 the Southern Hemisphere CZs appear when two necessary conditions in the mid-latitude
87 circulation are satisfied: (i) subtropical jet flows in the subtropical latitudes (30-35°S), and (ii)
88 low-level poleward flows prevail along the western peripheries of the subtropical highs (see also
89 Barreiro et al. 2002). A common denominator identified in all 3 Southern Hemisphere CZs is
90 therefore their association with mid-latitude wave trains, the vorticity centers of which elongate
91 along their equatorward flank, and interact with atmospheric instability to favor deep convection
92 over these regions (Widlansky et al. 2011; Macron et al. 2014; Van Der Wiel et al. 2015).

93 A fundamental difference however exists between the SPCZ on the one hand and both the SACZ
94 and the SICZ on the other hand. The former originates over what consists largely of open ocean,
95 and continental configuration and orography has been shown to have negligible influence on the
96 SPCZ orientation and intensity (e.g., Van Der Wiel et al. 2015). In contrast, both the SICZ and the
97 SACZ originate from continental landmasses. The SACZ originates in the Amazon basin, and is
98 considered part of the South American Monsoon System (see e.g. Carvalho et al. 2004). Figueroa
99 et al. (1995) showed that diabatic heating over the Amazon and the steep Andean topography are
100 both essential ingredients for the formation of the SACZ, while Lenters et al. (1995) attribute the

101 formation of the SACZ to the land–sea contrast in the absence of topography and longitudinal Sea
102 Surface Temperature variations (Barreiro et al. 2002). In both views, diabatic heating over the
103 continental landmass is a conditional mechanism for the formation of the SACZ.

104 The South Indian Convergence Zone (SICZ, Cook 2000) can be considered to correspond to the
105 time-integrated signature of synoptic systems called Tropical Temperate Trough (TTT, see e.g.
106 Todd and Washington 1998; 1999). TTT systems (and by extension the SICZ) appear to be
107 systematically associated with a mid-latitude transient perturbation, interpretable as an
108 atmospheric Rossby wave, coinciding with moisture convergence over tropical southern Africa.
109 The latter is related on one hand to the reinforcement of the so-called Angola low (forming over
110 the Angolan – Zambian region in summertime) that favors flux penetration from the Atlantic basin
111 toward southern Africa on the west and on the other hand to easterly moisture fluxes from the
112 nearby Indian Ocean and Mozambique Channel on the east (Macron et al. 2014). Cook (2000)
113 coins the term “Land-Based Convergence Zones” (LBCZ) to describe both the SACZ and the SICZ
114 and also argues that thermal lows over the land surface is necessary to sustain a root zone for the
115 LBCZs.

116 Because of the involvement of both tropical and mid-latitudes mechanisms in both the formation,
117 variability and maintenance of the SACZ and SICZ, it is reasonable to surmise that the SACZ and
118 the SICZ, and therefore rainfall variability in the South American and Southern African regions at
119 large, could potentially be connected, both via tropical teleconnection patterns and modes of
120 tropical variability (i.e. the ENSO at interannual time-scales, the Madden Julian Oscillation at
121 intra-seasonal timescales) as well as mid-latitude wave trains. To date however, very little attention
122 has been given to the potential (statistical and physical) relationships between these two regions.
123 Co-variability between the South American and Southern African regions (affected by the SACZ
124 and SICZ respectively), either synchronous or with some temporal lag, could however bear the
125 potential for improved predictability at various time-scales, a perspective of great importance
126 given the dependency of both South American and Southern African economies to rain-fed
127 agriculture (Mason and Jury 1997; Jury 2002; Reason and Jagadheesha 2005).

128 This issue provides the impetus for this study. In the present paper, we are interested in assessing
129 to what extent large-scale atmospheric convective variability over the African sector is connected
130 to the American region, and whether large-scale convective variability over Southern Africa and

131 nearby Indian Ocean could be anticipated using South American convection as a predictor. The
132 goals of the present study are to:

133 (i) assess and quantify climate co-variability between the Southern African and South
134 American regions, either synchronous or lagged, and at three different timescales : interannual,
135 intraseasonal and synoptic;

136 (ii) analyse whether co-variability between the two regions involves modulation in the
137 location and intensity of the SACZ and SICZ;

138 (iii) identify associated mechanisms and processes.

139 To that end, multivariate statistical methods maximizing the variance in each region and the
140 covariance between both regions are applied to a proxy of large-scale atmospheric convection.
141 Atmospheric dynamics and thermodynamics derived from current reanalyses are used to verify
142 that the modes of (co)-variability identified are not merely statistical artifacts and correspond
143 indeed to well-known modes of climate variability affecting these regions on timescales
144 investigated here.

145 This study is organized as follows. Section 2 presents the data and methodology used for this work.
146 Section 3 documents the results for each timescale (interannual, intraseasonal and synoptic).
147 Section 4 finally summarizes and discusses our main results.

148

149

150 **2. Data and methods**

151

152 *2.1 Datasets*

153

154 Daily tropical convection is estimated through the National Oceanic and Atmospheric
155 Administration (NOAA) interpolated outgoing longwave radiation (OLR) dataset (Liebmann and
156 Smith 1996), available daily on a 2.5 x 2.5 regular grid. The 1979 – 2012 period is considered in
157 this study. Fig. 1 shows the seasonal mean OLR field in austral summer (November through
158 February, NDJF hereafter) over a domain encompassing both the SACZ and the SICZ. In the
159 tropics, OLR is a good proxy for deep atmospheric convection. The most convectively active areas
160 of the region (Amazonia and Congo basins), as well as both CZ, are clearly discernible in Fig. 1.

161 Monthly SST are obtained from the HadISST dataset (Rayner et al. 2006) on a $1^\circ \times 1^\circ$ regular grid.
162 Only NDJF seasonal means and anomalies computed for the 1979 – 2012 period are used here.
163 Atmospheric fields are provided by the state-of-the-art European Centre for Medium-Range
164 Weather Forecasts ERA-Interim reanalyses (Simmons et al. 2007; Dee et al. 2011), available every
165 6 h since 1979 on a $0.75 \times 0.75^\circ$ regular grid. The fields used in this work are the horizontal (zonal
166 and meridional) wind components at 850 and 200hPa, which are among the most reliable variables
167 since they are directly constrained by data assimilation (refer to Kalnay et al. 1996 for more
168 details).

169 The state of ENSO is monitored using the Multivariate ENSO Index (MEI, Wolter and Timlin
170 1993). This bimonthly index, based on both atmospheric and oceanic fields (namely, sea-level
171 pressure, zonal and meridional components of the surface wind, sea surface temperature, surface
172 air temperature, and total cloudiness fraction of the sky), is adequate to describe the coupled nature
173 of the ENSO phenomenon. All the input variables cited above are taken from the International
174 Comprehensive Ocean-Atmosphere Data Set (ICOADS).

175 The MJO signal is represented by the real-time daily indices developed by Wheeler and Hendon
176 (2004, hereafter referred to as WH04). The indices are the time series of the two leading
177 eigenvectors of a Principal Component Analysis (PCA) of combined daily mean tropical (averaged
178 15°N – 15°S) anomalies of 850 and 200hPa zonal wind (derived from NCEP/NCAR reanalyses,
179 Kalnay et al. 1996) and the NOAA interpolated OLR. WH04 subtracted the annual cycle and the
180 low-frequency variability associated with ENSO before applying the PCA. The indices, denoted
181 real-time multivariate MJO (RMM1 and RMM2), were designed to be used in real time and to
182 capture both the northern winter and summer MJO. RMM1 and RMM2 are approximately in
183 quadrature and describe the average large-scale, eastward-propagating convective and circulation
184 anomalies associated with the MJO.

185

186 *2.2 Methods*

187

188 Co-variability between the South American and Southern African regions is documented in this
189 work through Canonical Correlation Analyses (CCA hereafter). CCA can be used to identify the
190 most energetic modes of co-variability between two variables or sets of variables. In this study,
191 CCA is applied on OLR data extracted over the South American and Southern African regions

192 (see domain definition in Fig. 1). The definition of the South American domain (AM hereafter) is
193 inspired by the anomaly patterns discussed in Carvalho et al. (2004) and more recently Jorgetti et
194 al. (2014). Its counterpart for Southern Africa (AF) is that already used e.g. in Todd and
195 Washington (1999), Fauchereau et al. (2009) or Vigaud et al. (2012). Preliminary tests were made
196 to ensure the robustness of the detected modes of co-variability and their sensitivity to the choice
197 of these domains; particular attention was given to the possible decouplings between the oceanic
198 and continental parts of the South American domain (Carvalho et al. 2002a; 2004; 2011). Results
199 (not shown) reveal a good stability of the main modes. Prior to the CCA decompositions, and
200 depending on the timescale investigated (intraseasonal or synoptic), we used a Butterworth
201 temporal filter to retain characteristics timescales of interest. Additional analyses based on Lanczos
202 or digital filters led to qualitatively similar results and alter none of our conclusions, suggesting
203 weak sensitivity to the filtering procedure (not shown). We also used temporal lags between the
204 two regions to take into account potential propagations of convective anomalies or atmospheric
205 waves from one sector to another. Further details are provided below. In order to further ensure
206 the consistency of the modes of co-variability identified by the CCA, the latter are also compared
207 to the main modes of OLR variability over each region, such as extracted by PCA applied to each
208 domain separately. Results are discussed in the following sections and in the Appendix. In the
209 following, we choose to present only the first mode of co-variability for each timescale. This is
210 because (i) the first mode are clearly distinguishable over other ones (almost two times more co-
211 variance explained compared to the second modes for each timescale), and (ii) the second modes
212 show spatial and temporal patterns that are more ambiguous and less easy to interpret,
213 corresponding to no well-known mode of variability (Appendix) influencing both regions, which
214 questions thus their physical robustness. Finally, the sensitivity to the domain size and location
215 was addressed by a series of preliminary analyses (some of which consisting in separating the
216 oceanic and continental parts of each domain). Results revealed remarkably stable modes of co-
217 variability for the three timescales presented and discussed below.

218

219

220 **3. Results**

221

222 *3.1 Interannual timescale*

223

224 In order to quantify climate co-variability between both domains at the interannual timescale, a
225 CCA is applied in this section on the seasonal mean OLR fields during austral summer (NDJF)
226 from 1979 to 2012. Only the first mode of co-variability extracted from the CCA is described here
227 (Fig. 2). It explains about 42% of the total covariance between the two domains. Associated time
228 series display a strong positive correlation ($R > 0.75$, $p\text{-value} < 0.01$) denoting a clear tendency for
229 seasonal anomalies to occur in phase between the two sectors. They show no or weak
230 autocorrelation (i.e. persistence from one year to another), as estimated by the methodology of Der
231 Megreditchian (1992, which estimates the actual number of degrees of freedom in a given time
232 series), even though they could possibly show a long-term trend towards positive values (not
233 significant for the “AM” time series, only significant at 90% in the African sector according to a
234 Spearman test).

235 Spatially, the regions of largest loadings (Fig. 2) show:

236 (i) for the American domain, a meridional dipole between northern Brazil and southeastern Brazil
237 / northern Argentina, the latter region being connected to the Southern Atlantic basin through a
238 NW-SE oriented alignment. The latter is located too far south compared to the typical location of
239 the SACZ such as reported in the studies cited above.

240 (ii) over the African domain only the southwestern and northeastern parts of the domain (i.e. the
241 southern Atlantic and tropical Indian Oceans) show significant co-variability with American
242 convection, in phase (out of phase) with the southern (northern) pole of the South American dipole
243 discussed above; correlations are not significant over Southern Africa and the SWIO (that is, the
244 climatological location of the SICZ).

245 Over both sectors, the spatial patterns of this mode of co-variability are strongly reminiscent of
246 regional effects of ENSO on large-scale convective variability in austral summer. Such high co-
247 variability is presumed to result from the common influence of a mode of large-scale climate
248 variability.

249 At the interannual timescale, ENSO is clearly the dominant mode of variability in the tropics and
250 has been shown to affect significantly both regions. For South America, seasonal dry conditions
251 over northern Brazil and wet anomalies further south are usually observed during El Niño austral
252 summers (Grimm et al. 2000; Cazes-Boezio et al. 2003; Krishnamurthy and Misra 2010). In
253 Africa, El Niño is associated with wet anomalies in Equatorial East Africa (e.g., Nicholson 2015),

254 northern Madagascar and the adjacent SWIO, contrasting with dry conditions in continental
255 Southern Africa (Fig. 4f). There, regional ENSO effects are non-linear (Reason and Jagadheesha
256 2005; Fauchereau et al. 2009), as illustrated by the contrasted effects of the very strong 1982-83
257 and 1997-98 events (e.g., Lyon and Mason 2007; Boulard et al. 2013).

258 However, the degree to which the SACZ and SICZ *stricto sensu* are modulated by ENSO is open
259 to interpretation. Robertson and Mechoso (2000) suggest that interannual variability of the SACZ
260 is largely independent from ENSO, while Carvalho et al. (2002a) indicate that extreme rainfall
261 events associated with intense convection in the SACZ is modulated by ENSO. Moreover,
262 Carvalho et al. (2004) moreover indicate that a persistent SACZ with a well-defined oceanic
263 (continental) activity is favored during warm (cold) ENSO episodes. Barreiro et al. (2002) also
264 show that part of the SACZ variability is remotely forced by Pacific SSTs, with a response notably
265 consisting of a northeastward shift of the SACZ with associated rainfall anomalies during warm
266 ENSO events. Over Southern Africa, El Niño has been reported to shift eastwards the SICZ. Cook
267 (2001; 2003) proposed that ENSO generates atmospheric Rossby waves in the Southern
268 Hemisphere which could be responsible for such a longitudinal shift, hereby explaining the
269 seasonal droughts typically associated with El Niño events in Southern Africa. In contrast,
270 Nicholson (1997) and Nicholson and Kim (1997) find a predominant oceanic forcing, warm SST
271 anomalies over the Indian Ocean acting to shift convective activity over the SWIO. Misra (2003)
272 partly reconciled these two hypotheses by estimating that the spatial structure of SA rainfall
273 anomalies is mainly dependent on regional Indian Ocean SST, while their amplitude is modulated
274 by large- scale atmospheric Rossby waves.

275 Concerning interannual co-variability, even though the patterns of Fig. 2 are fairly consistent with
276 the typical signature of ENSO over these regions, it is worth noting that the canonical ENSO
277 pattern over Southern Africa usually shows larger correlations than those found in Fig. 2 (see Fig.
278 4f and e.g., Lyon and Mason 2007; Fauchereau et al. 2009; Lyon and Mason 2009; Pohl et al.
279 2009), suggesting first a partial influence of ENSO interfering here with other mechanisms (such
280 as e.g. the seasonal anomalies of the so-called “Angola Low”, invoked in Reason and Jagadheesha
281 2005 to explain the non-systematic effects of ENSO over the southern tip of the African continent).
282 Second, the correlation coefficient between the time series associated with each domain and the
283 MEI is even slightly higher than that between the two domains, hereby indicating that roughly
284 60% of their variance linearly relates to the state of ENSO. Third, a partial correlation between the

285 time series derived from the CCA after removing the influence of ENSO decreases to 0.36 (not
286 shown; still significant at the 98% level), denoting a dominant (but not exclusive) role of ENSO
287 at this timescale.

288 Some insights on the mechanisms responsible for this mode of co-variability are proposed in the
289 following. The correlations between mean horizontal wind at 200hPa and 850hPa and OLR are
290 displayed in Figs. 3-4. Results presented here corroborate Boulard et al. (2013): ENSO acts to shift
291 polewards the mid-latitude westerlies (which are thus weakened at the subtropical latitudes and
292 enhanced south of 50°S). Negative correlations with the OLR at the subtropical latitudes (Fig. 4f)
293 suggest larger cloud fractions during El Niño events, although the accuracy of OLR as an indicator
294 of upper-layer cloud cover (probably both stratiform and convective) is reduced there compared
295 to the tropics. Very similar wind and OLR correlations (of opposite sign) are obtained with the
296 AM and, to a lesser extent, the AF time series. Similarities with the MEI are stronger for the AM
297 series, consistently with Fig. 2. Although all time series lead to very similar variability patterns
298 over the American sectors, clear and spatially-coherent convective signals over Southern Africa
299 are only found for the AF time series. The MEI is associated with weaker results there (Fig. 4f)
300 and the AM time series shows no significant association with the interannual variability of OLR
301 over Southern Africa (Fig. 4g). The anticyclonic / cyclonic cells are however located quite
302 similarly for all indices (Fig. 3). They mostly consist on an enhancement of the South Atlantic
303 (Saint Helena) High and reduced poleward export of momentum over South America and Southern
304 Africa during El Niño conditions. These features correspond well to the regional effects of ENSO
305 over these sectors.

306 While ENSO's influence on the co-variability between the Southern American and South African
307 regions at interannual timescale is dominant, other modes of climate variability could potentially
308 be involved in the co-variability patterns previously identified. In addition to the results above,
309 Figs. 4d-e and 4i-j present teleconnections between, on the one hand, global SST and regional
310 OLR, and on the other hand, the AF and AM time series, after removing ENSO influence (shown
311 in Figs. 4a,f). Results confirm the primary role of ENSO for both regions (Figs. 4a-c and 4f-h), but
312 also suggest a secondary influence of:

313 (i) local / regional SST in the oceans adjacent to both regions (i.e. Southwest Atlantic for the
314 American sector, subtropical Indian Ocean for Southern Africa). For the latter, the pattern

315 identified is reminiscent of the so-called “Subtropical Dipole” identified by Behera and Yamagata
316 (2001), although its eastern pole off Australia is barely significant.

317 (ii) regional-scale anomalies in the OLR field. For the AM time series, they emerge over the
318 Southern Atlantic and tropical Africa, which suggests that the interannual variability of the mid-
319 latitude dynamics is partly decorrelated with ENSO, and directly influence southern South
320 America. For the AF time series, similar conclusions are raised for large-scale atmospheric
321 convection over the western Indian Ocean at tropical latitudes. This signal is not associated with
322 clear SST variability (Fig. 4e) and should be interpreted with caution.

323 To sum up, co-variability in the large-scale convection between South America and Southern
324 Africa at the interannual timescale is mostly, but not only, due to the common influence of ENSO.
325 Consequently, associated patterns resemble more the regional ENSO effects over each sector than
326 the CZ present over each region.

327

328 *3.2 Intraseasonal timescale*

329

330 A CCA is here applied to daily OLR anomalies (after removal of the average annual cycle)
331 computed over the same domains as Fig. 2. Prior to the analysis, input data were bandpass-filtered
332 to retain the frequencies comprised between 25 and 75 days, with a 10-day lag period between the
333 two regions (i.e., South America leads Southern Africa by 10 days). These filtering and lag
334 parameters were set by a series of preliminary tests (not shown), which aimed at identifying robust
335 and coherent modes of co-variability between the two regions.

336 The corresponding first mode of intraseasonal co-variability is shown in Fig. 5. It explains about
337 32% of the total intraseasonal co-variance between both domains. As for the interannual timescale
338 (Section 3.1), these co-variability patterns are not clearly related to the SACZ and SICZ. The
339 strongest signals are confined in the low latitudes (north of the Tropic of Capricorn), and are both
340 weaker and noisier in the mid-latitudes. Associated time series show rather high correlation over
341 the period ($r = 0.51$), significant at the 99.99% confidence level considering their autocorrelation
342 strongly reducing the degrees of freedom of both time series.

343 The frequencies at which the co-variability between the two regions is maximized are strongly
344 reminiscent of the Madden-Julian Oscillation (MJO, Madden and Julian 1971; Madden and Julian
345 1972; Madden and Julian 1994; Zhang 2005), the leading mode of climate variability in the tropics

346 at the intraseasonal timescale. The MJO has already been shown to exert a significant influence
347 over both regions (e.g., Carvalho et al. 2004 for South America ; Pohl et al. 2007 for Southern
348 Africa). This is thus a potential candidate to explain the climate co-variability between both
349 regions, even though this point has not been addressed *per se* in the literature so far. Two distinct
350 supporting facts further reinforce the hypothesis of the MJO influence: (i) the MJO is a mode of
351 tropical variability, modulating deep atmospheric convection mostly in the low latitudes, and its
352 effects over both regions match well the spatial patterns shown in Fig. 5a (Carvalho et al. 2004;
353 Pohl et al. 2007); (ii) the largest covariance between the two sectors is obtained for a lead-time of
354 10 days, matching once again the phase speed of the MJO: South America and Southern Africa
355 being shifted by roughly 90° in longitude, it gives a period of about 40 days for the whole cycle –
356 even though the MJO phase speed itself is not constant over all longitudes, see e.g. Salby and
357 Hendon (1994); Bantzer and Wallace (1996); Matthews (2000).

358 Casarin and Kousky (1986) showed that a SACZ episode appears about 15 days after a SPCZ
359 (Kuhnel 1989) episode, apparently through the propagation of the MJO. We aim here at clarifying
360 this point for the two regions analyzed in this work (Figs. 5b-c). Fig. 5b first presents composite
361 anomalies of the time series obtained from the CCA for the 8 phases of the MJO as defined by the
362 RMM indices computed by WH04. The scores tend to be significantly negative (denoting
363 enhanced convection in the tropical part of our domains) for phases 1-3 (during which the large-
364 scale convection associated with the MJO initiate and develop over the western and central Indian
365 Ocean) and positive (suppressed convection in tropical America and Africa) for phases 5 to 8
366 (suppressed convection over the Indian Ocean and enhanced convection over the Western Pacific
367 and next weakening while propagating eastwards). It should be recalled that the signals appear
368 perfectly in-phase between South America and Southern Africa, since the OLR time series were
369 shifted by 10 days prior to the CCA. These results therefore do not suggest in-phase modulation
370 of atmospheric convection by the MJO over the two regions.

371 Fig. 5c shows cross-spectral analyses between the same score time series and the RMM1 principal
372 component. Similar results could be obtained using RMM2 instead, but with a phase relationship
373 shifted by 90° . Results confirm significant associations between both CCA time series and RMM1
374 for periodicities comprised between roughly 15-20 days and >100 days. At timescales from 30 to
375 60 days, the CCA time series share about 40% of their variance with RMM1. This confirms the
376 predominant (but not exclusive) influence of the MJO on this mode of co-variability between the

377 two regions and quantifies the fraction of the time series variance that directly relates to the MJO.
378 As for the interannual timescale, the co-variability between South America and Southern Africa
379 (i) does not directly involve the SACZ and SICZ *stricto sensu*, (ii) mainly results from the
380 influence of a mode of large-scale variability (here the MJO) affecting both regions.
381 Further analysis of associated atmospheric dynamics and deep convective activity is given in Figs.
382 6, 7 and 8, respectively presenting the regional-scale circulation and OLR anomaly patterns
383 associated with fluctuations in the AM and AF time series, together with composite anomalies
384 based on RMM indices and describing the canonical signature of the MJO over the region. For the
385 AM and AF analyses, the composites are constructed by extracting the extreme positive and
386 negative phases (± 1 standard deviation) of the time series shown in Fig. 5, and next plotting the
387 synchronous and lagged differences in OLR and wind anomalies. The lags introduced, spanning
388 between -25 and +25 days, are chosen to document roughly the life cycle of an MJO event.
389 Over South America, episodes of enhanced convection (between Day 0 and Day +20, Fig. 6) are
390 concomitant with a transient enhancement of the South Atlantic High throughout the troposphere;
391 over the Amazonia basin it is also associated with lower-layer northwesterly anomalies. These
392 patterns are roughly opposite to those associated with the suppressed convection prevailing
393 between Day -15 and Day 0, i.e. before the peaks in the AM time series of Fig. 5. They are
394 consistent with the intraseasonal anomalies found to recurrently modulate large-scale convection
395 over the region in Carvalho et al. (2002a; 2002b). Also interesting is the fact that, between Day +5
396 and Day +15 (i.e. a few days after the development of convection in South America), negative
397 OLR (active convection) and lower-layer northwesterly anomalies similarly develop over the
398 Southern African sector. Dry anomalies symmetrically develop there between Day -15 and Day 0,
399 lagging once again the positive OLR anomalies over South America. The wet episodes over South
400 America are reminiscent of the anomalies associated with MJO phases 8 and 1 (Fig. 8), i.e. those
401 associated with enhanced convection over the western Hemisphere and Africa (WH04, their Fig.
402 7). It is worth noting that, in agreement with previous studies, atmospheric dynamics associated
403 with the MJO extends in the mid-latitudes (Matthews and Meredith 2004; Pohl et al. 2010) and
404 even high southern latitudes (Flatau and Kim 2013; Fauchereau et al. 2016), even if associated
405 convective anomalies are confined to the tropics and involve no clear continuities with the extra-
406 tropics (Figs. 5a, 6-7-8). Moreover, the similarity between the “canonical” MJO signature over the
407 region and the wet / dry phases over South America is not perfect, which suggests that the MJO

408 drives only part of the regional convective intraseasonal variability (40% according to Fig. 5b,
409 indicating that other phenomena independent from the MJO are involved in the intraseasonal
410 variability and co-variability such as extracted here). A potential candidate is the South Atlantic
411 High, which shows variability only partly related to the MJO, and influences mass flux
412 convergence over tropical South America. Indeed, the anomaly patterns shown in Fig. 6 match
413 very well those found in Carvalho et al. (2004) to correspond to “intense” and “weak” SACZ
414 events (referred to as wet and dry phases in this study, respectively), hereby suggesting a non-
415 negligible intrinsic variability that develops at the local / regional scales. Numerical ensemble
416 experiments performed e.g. with a regional climate model used in the CLARIS / South America
417 CORDEX framework (Solman 2013) should allow disentangling the large-scale versus regional-
418 scale fractions of convective variability in this region.

419 For Southern Africa (Fig. 7), enhanced convection (Day0 to Day +20) is associated with lower-
420 layer easterly anomalies favoring moisture advections from the Indian Ocean towards Africa. They
421 first develop over the west coast of Southern Africa before migrating eastwards and next
422 northwards. This corresponds to the signature of the MJO there (Fig. 8, phases 6 to 1). Opposite-
423 sign patterns prevailing between Day -15 and Day 0 (Fig. 7) are similarly close to the MJO phases
424 2 to 5, associated with dry anomalies (Fig. 8). In agreement with Fig. 6, largest convective
425 anomalies (of both signs) tend to develop over Southern Africa a few days after their largest
426 intensities over South America. The symmetry between the two regions is thus rather evident,
427 albeit not perfect. For both regions, the influence of the MJO is thus predominant, but more
428 regional phenomena and mechanisms influence both regions separately and act to decouple their
429 variability at the intraseasonal timescale. As for the South American sector, Southern African
430 convective anomalies at the intraseasonal timescale are associated with temperate anomalies over
431 the South Atlantic, but also circulation anomalies over the Indian Ocean, both influencing large-
432 scale convergence over the region. Due to such interferences with regional-scale climate
433 variability, both AF and AM series share only 30-40% of their total variance, at intraseasonal
434 timescales, with the global-scale MJO (Fig. 5c).

435 In short, the main result in this section is similar to the interannual timescale: a significant but
436 partial influence of a mode of large-scale variability, namely the MJO, is here responsible for
437 convective co-variability between the two regions at the intraseasonal timescale. In the mid-
438 latitudes, variability of the South Atlantic High associated with the MJO appears as a key

439 circulation pattern modulating mass flux convergence and thus convective activity over both
440 regions.

441

442 *3.3 Synoptic scale*

443

444 This section corresponds to the most novel contribution of the present study. As for the
445 intraseasonal timescale, a series of preliminary analyses were conducted using various band-pass
446 filters and lags in order to find the modes maximizing the co-variance between the two regions.
447 However, unlike previous timescales, for which the most appropriate choice was quite evident,
448 two robust modes of co-variability emerged when filtering input OLR data so that synoptic
449 variability is retained (that is, using a 10-day highpass filter). The most robust mode is found for
450 synchronous co-variability between South America and Southern Africa (i.e. in-phase convective
451 fluctuations in both regions). A second, slightly weaker mode is found for a lag of 4 days (South
452 America leads Southern Africa); this mode has been recently identified and discussed by Grimm
453 and Reason (2015).

454 For conciseness, only the first mode is analyzed in details here (Fig. 9), and we will only discuss
455 briefly the second one. Contrary to results presented for the interannual and intraseasonal time-
456 scales, the regions showing significant co-variability at the synoptic timescale match well the
457 typical spatial signature of both CZ (i.e., the SACZ in South America and the SICZ in Southern
458 Africa, see the Introduction). It is also worth noting that these spatial patterns correspond well to
459 the dominant modes of large-scale convective synoptic variability when extracted over each region
460 separately (see the Appendix). Convective signals co-vary in phase between the two sectors, but
461 share a sensibly lower fraction of variance compared to the intraseasonal timescale ($R = 0.25$).
462 This is due to the larger number of DOF (Fig. 9) and the noisier character of associated time series.
463 Yet, the latter are still correlated at a 99.99% significance level (even when considering their serial
464 autocorrelation). Over the American domain, the largest co-variance is found over the oceanic part
465 of the region, that is the Southern Atlantic, along a northwest-southeast oriented band clearly
466 reminiscent of the SACZ structure. That is, the oceanic part of the domain exhibits largest co-
467 variance with African convection than the continental part. Over Southern Africa, similar
468 alignments prevail, which are also in good agreement with the spatial signature of the SICZ (or

469 TTT systems when synoptic time-scales are exclusively considered). There, land-sea contrasts are
470 of weaker importance.

471 Associated atmospheric dynamics and convection are shown in Figs. 10 and 11. They are obtained
472 as lagged composite analyses between the opposite phases of the AM and AF series shown in Fig.
473 9, respectively. Episodes of enhanced convection over South America are embedded in a wave
474 train well discernible two days before the convective burst. Associated wind and convective
475 anomalies develop and peak at Day 0 (synchronously with the local maxima of the AM time series)
476 and gradually elongate from northwest to southeast before weakening (Day +2 to +4) and
477 dissipating (Day +6). This structure, already described in *e.g.* Van der Wiel et al. (2015), is clearly
478 reminiscent of an atmospheric Rossby wave triggering convection through baroclinic instability.

479 The same pattern and the same mechanisms are found over the Southern African sector. The
480 development, peak and decay of vorticity anomalies are synchronous between both regions (with
481 largest wave amplitudes found between Day -2 and Day +2).

482 Comparing Figs. 10 and 11 reveals that each sector is influenced by an atmospheric Rossby wave
483 modulating its atmospheric convection, but with no clear association with the remote region –in
484 other words, anomalies are weak, on average, over Southern Africa during AM events, and South
485 America during AF events. This may seem as counter-intuitive, since the time series extracted
486 from the CCA (Fig. 9) are associated with a mode designed to maximize co-variability between
487 the two regions. This is due to the intermittency of the co-variability between the AF and AM
488 regions (Table 1). Only $\frac{1}{4}$ of the convective bursts in the AM domain (143 days out of 608) are
489 associated with a synchronous burst in the AF region, and the same fraction is also verified for the
490 clear-sky conditions in both regions (165 days out of 612). This intermittency contributes to
491 explain the relative weakness of the positive correlation between both time series (Fig. 9). Yet,
492 Table 1 confirms that they clearly tend to co-vary in phase. Very few days are characterized by
493 synchronous out-of-phase convective anomalies between the two sectors (59 show active
494 convection in AM and suppressed convection in AF, and 49 the other way around).

495 Fig. 12 shows the composite analyses of atmospheric dynamics and convection during the joined
496 and synchronous phases of both AM and AF time series. The resulting pattern roughly corresponds
497 to the union of those shown in Figs. 10 and 11, *i.e.*, they combine the vorticity over both sectors
498 through a continuous wave train over the whole South Atlantic, linking both CZ, and modulating
499 large-scale atmospheric convection over both sectors. Although it is too rare to appear on average

500 when working on each sector specifically, this continuous wave train is shown here (Table 1, Fig.
501 12) to contribute to about 25% of the active AM and AF events and is thus non-negligible to
502 explain their overall temporal variability. These results are consistent and complement those
503 obtained by idealized numerical experiments by Cook et al. (2004)

504 To sum up, synchronous convective bursts between both regions at short timescales are due to the
505 development of a wave train in the mid-latitudes. This is an intermittent phenomenon, which
506 occurs on average during only one quarter of the convective burst of each region, the remaining
507 ones showing no concomitant anomalies over the remote region. The same conclusions hold for
508 opposite sign anomalies, that is, synchronous clear sky conditions developed over both sectors.
509 The predominance, for the synoptic scale, of this “synchronous” mode of variability (Fig. 9)
510 against a weaker (yet significant) mode with a 4-day-lag between the two regions (Grimm and
511 Reason 2015), suggests that the development of the wave train over the South Atlantic is more
512 frequent and accounts for a larger part of the co-variability between the two regions, than other
513 mechanisms involving wave propagations over the sector (such as a baroclinic instability
514 developing over the AM region, next propagating eastwards and finally modulating atmospheric
515 convection a few days later over Southern Africa). Such phenomena are nevertheless thought to
516 have a physical reality, even though it is of weaker importance for both regions. It is thus not
517 discussed in details in the present study.

518

519 *3.4 Scale interactions*

520

521 Fig. 13 finally presents results illustrating the scale interactions between the various timescales
522 and regions analyzed and discussed in the previous sections.

523 ENSO has already been shown to interact with intraseasonal (Pohl and Matthews 2007) and
524 synoptic-scale (Carvalho et al. 2004; Fauchereau et al. 2009; Pohl et al. 2009) variability over both
525 regions. More precisely, ENSO tends to favor (i) higher-frequency (i.e. shorter) MJO events (Pohl
526 and Matthews 2007); (ii) spatial shifts in the location of both CZ, which translates into interannual
527 modulations of the synoptic-scale convective bursts over both continents. Figs. 13a-d indicates to
528 what extent ENSO modulates the seasonal variance of the high-frequency modes of co-variability
529 shown in Figs. 5 and 9.

530 None of the scale interactions involving ENSO is statistically significant (at the 95% level). One
531 can only conclude that intraseasonal convective variability tends to be larger over both regions
532 during El Niño conditions, a result already suggested by Pohl et al. (2007) over Southern Africa.
533 The strongest relationship identified here concerns synoptic-scale variability over South America,
534 also found to be stronger than normal during El Niño (Fig. 13a). There is no equivalent for
535 Southern Africa: while ENSO modulates the “continental” (i.e. westernmost) TTTs embedded in
536 the SICZ, it seems to impact their only location (i.e. during El Niño, TTT are shifted eastward)
537 rather than their overall frequency.

538 Relationships between intraseasonal (MJO) and synoptic-scale variabilities are next assessed
539 through cross-spectral analyses (Figs. 13e-h). Pohl et al. (2009) previously concluded on the lack
540 of clear and significant scale interactions at these time-scales over Southern Africa. More recently,
541 Oettli et al. (2014) and Hart et al. (2013) suggested possible (but weak) relationships, consisting
542 in a modulation by the MJO of the intensities (but not their location nor their frequency) of TTTs
543 over Southern Africa. The analyses carried in this work tend to support the conclusions of Pohl et
544 al (2009) and do to show any significant relationships between these timescales (Figs. 13g-h). Note
545 however that the methodologies used here are not able to capture explicitly the intensity of synoptic
546 systems such as TTTs.

547 Figs. 13e-f finally document the relationships between the two regions, based on the
548 “intraseasonal” and “synoptic” time series (resp. shown in Figs. 5 and 9). Confirming previous
549 results, the two time series show up to 50% of common variance at the typical frequencies of the
550 MJO (Fig. 13e). As stated above, even though they are influenced by a common mode of large-
551 scale variability, both regions nonetheless show some non-negligible intrinsic variability. The
552 latter should however not be overestimated, the MJO being “active” only about 50% of the time
553 (WH04). The common variance is weaker for the synoptic scale (Fig. 13f), peaking at most at
554 30%. This is presumably due to the intermittent nature of the co-variability between the two sectors
555 at this timescale (Table 1). Yet, statistical associations between the two regions are significant for
556 frequencies higher than 10 days, a logical result given the settings of the filter used for this
557 timescale.

558
559

560 **4. Conclusion and discussion**

561

562 This study aimed at characterizing patterns of co-variability between South American and
563 Southern African large-scale atmospheric convection at various timescales (ranging from synoptic
564 to interannual), and identifying associated mechanisms and processes. The main results can be
565 summarized as follows:

566 (i) At the interannual timescale, both regions are influenced by ENSO and tend to co-vary in phase.
567 Both tropical Africa (including Equatorial East Africa) and southeastern Brazil / northern
568 Argentina tend to experience wetter than normal conditions during El Niño. Southern Africa and
569 northern Brazil tend to record opposite anomalies. The influence of ENSO in Southern Africa
570 being complex and not systematic (Reason and Jagadheesha 2005), the co-variability pattern
571 identified in this work is not significant over that area. This indicates that ENSO influence,
572 although strong and highly significant, interferes with other phenomena / modes of variability at
573 this timescale, including e.g. the Subtropical Dipole over the Indian Ocean (Behera and Yamagata
574 2001) or more local variability patterns in the Southern Atlantic or Indian basins. 60% of the
575 interannual variability in each American and African region linearly relates to the state of ENSO
576 and these two regions share also about the same percentage of variance.

577 (ii) At the intraseasonal timescale, both regions are once again placed under the common (but
578 partial) influence of a mode of large-scale climate variability, namely, the MJO. Large-scale
579 convective anomalies over South America, either positive or negative, lead those of Southern
580 Africa by 10 days (i.e. roughly $\frac{1}{4}$ of the typical MJO life cycle). At the typical frequency bin of
581 the MJO (30-60 days), both regions show about 35-40% of common variance with a global-scale
582 MJO descriptor, and share about 50% common variance. In both areas, deep convective anomalies
583 solely concern the tropical part of the domain, the temperate latitudes showing nonetheless strong
584 dynamical signals consisting mostly in an intraseasonal modulation of the South Atlantic High.
585 The latter seem to be particularly relevant to influence mass flux convergence over both sectors,
586 and thus large-scale convective variability. Part of its variability is related to the MJO (hereby
587 confirming previous work, e.g. Matthews and Meredith 2004), but such circulation anomalies also
588 account for a (limited) fraction of extra co-variability.

589 (iii) At the synoptic scale co-variability is weaker and the time series associated with each region
590 are much noisier. They show only 6% of common variance. The spatial patterns however
591 correspond well to the spatial signatures of the SACZ and SICZ. Importantly, convective

592 anomalies tend to occur synchronously in the two sectors, i.e., in-phase enhanced or suppressed
593 convection occur in both CZ. Physically, large-scale convective activity in each region is triggered
594 by atmospheric Rossby waves in the mid-latitudes. In-phase convection between the two regions
595 occurs only 25% of the time, the remaining 75% corresponding to a transient enhancement or
596 suppression of convection over one sector without any significant changes over the remote region.
597 When both regions show in-phase anomalies, it is associated with a continuous wave train
598 developing over the Southern Atlantic and linking America and Africa. In the other cases, the wave
599 train is interrupted between the two longitudes, over the Atlantic Ocean, and atmospheric
600 convection is thus significantly modified over one single continent. In the end, at timescales longer
601 than ~10 days, South American and Southern African convection can show up to 20-30% of
602 common variance, a magnitude intuitively coherent with the fact that $\frac{1}{4}$ of the Rossby waves
603 triggering convection over one given region is accompanied by another one located at the same
604 time over the second sector. Our results also suggest that another mode of co-variability relates
605 both regions at this timescale, and consists in deep convective anomalies developing first over the
606 American region and next, four days later, over Africa. This mode, which could be interpreted as
607 the propagation of a Rossby wave over the Southern Atlantic, seems however to be weaker and
608 less robust than the synchronous mode detailed and presented in this work. It is also thought to
609 account for a more limited amount of common variance between South America and Southern
610 Africa.

611 (iv) Finally, scale interactions between the aforementioned scales and phenomena are investigated.
612 Results suggest possible (but barely significant) intensification of intraseasonal variability over
613 both South America and Southern Africa during El Niño events. Possible modulation of synoptic-
614 scale variability by ENSO is also suggested over the American region only. No significant
615 relationship is found between the intraseasonal and synoptic scales, i.e. the occurrences or co-
616 occurrences of Rossby wave(s) over our two domains do not seem to be strongly modulated by the
617 phase of the MJO within the tropics.

618 Our results contribute to a better understanding of the factors that influence regional-scale
619 convective fluctuations in the South American and Southern African sectors. They also provide a
620 clearer picture of the co-occurrences of cloud bands over the Southern Hemisphere, clearly visible
621 over satellite images of the Southern Hemisphere, and about which little is known. In future work,
622 transposing such analyses to the third convergence zone of the Southern Hemisphere, namely the

623 South Pacific Convergence Zone (SPCZ), could complete the picture of the variabilities and co-
624 variabilities affecting and modulating the intensity, extension and location of these zones.

625
626

627 **Appendix. Dominant modes of large-scale convective variability in each region**

628

629 The Canonical Correlation Analyses used in this work aim at maximizing the co-variability
630 between two domains. The modes extracted could possibly differ from the leading modes of
631 variability calculated for each region separately. This case would imply that the mode extracted
632 probably accounts for a reduced fraction of the regional climate variability in each region and
633 could thus correspond more to a statistical artifact than a physically robust mechanism.

634 Figs. S1 and S2 present therefore the leading EOF of PCA applied to raw (unfiltered) OLR
635 anomalies in each region. Both analyses extract the robust variability patterns, already presented
636 in many previous papers for both regions (e.g., Carvalho et al. 2004; Pohl et al. 2009), which are
637 associated with the spatio-temporal variability of both CZ. These patterns sensibly differ from
638 those found at the interannual (Fig. 2) and intraseasonal (Fig. 5) timescales, which are discussed
639 in this study. The latter are however in fair agreement with the spatial signature of ENSO and the
640 MJO over these sectors, respectively, which confirms the hypothesis of significant co-variabilities
641 caused by the common influence of a single, larger-scale atmospheric or climatic phenomenon
642 encompassing both regions.

643 The spatial similarity is largest for the synoptic scale, counter-balancing a weaker and intermittent
644 temporal co-variability. For this timescale, one can thus conclude that the mode of co-variability
645 shown in Fig. 9 corresponds to the leading variability patterns influencing each region. Unlike the
646 longer timescales, one can here conclude on co-variability between the “SACZ” and “SICZ”,
647 strictly speaking, and not merely on the South American and Southern African regions.

648
649

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651

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820

821 **Figure Captions**

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823 **Figure 1** Study domain for the "South American" sector (in blue: 50°S-0°, 70°W-10°W) and
824 "Southern African" sector (in red: 40°S-10°S, 7.5°E-70°E), as well as the large region
825 encompassing both domains. Shadings represent the austral summer (November through
826 February) seasonal mean OLR field ($W m^{-2}$).

827

828 **Figure 2** Canonical correlation analysis of seasonal mean OLR co-variability at the
829 interannual timescale between the "South American" and "Southern African" sectors, period NDJF
830 1979-2012. Upper panels: first mode of co-variability, displayed through heterogeneous
831 correlation maps. Dashed curves show the 95% significance bound according to a Bravais-Pearson
832 test. The squared coherence fraction (SCF) is labeled in the figure. Lower panel: associated time
833 series, represented together with the seasonal mean Multivariate ENSO Index (MEI, multiplied by
834 -1 for readability) over the same period. The correlation matrix between these time series and their
835 actual number of degrees of freedom (considering possible serial auto-correlation) are indicated in
836 the figure.

837

838 **Figure 3** Interannual correlations between the seasonal mean and horizontal wind at 200hPa
839 (left-hand panels) and 850hPa (right-hand panels), and the three time series shown in Fig. 2. Only
840 95% significant correlations according to a Bravais-Pearson test are displayed.

841

842 **Figure 4** (a) Interannual correlations between the seasonal mean SST and synchronous MEI,
843 period NDJF 1979-2012. Black contours show 95% significant correlations according to a Bravais-
844 Pearson test. (b, c) As (a) but for the AM and AF time series of Fig. 2, respectively. (d, e) As (b,c)
845 but after removing linearly the influence of the synchronous MEI. (f-j) As (a-e) but correlations
846 with the seasonal mean OLR field over the domain shown in Fig. 1.

847

848 **Figure 5** (a) Canonical correlation analysis of 25-75-day bandpass filtered (intraseasonal)
849 OLR co-variability between the "South American" and "Southern African" sectors, period NDJF
850 1979-2012. Upper panels: as Fig. 2, upper panels. A lag of 10 days is here applied between the
851 two regions (South America leads Southern Africa by 10 days). Central panel: associated time
852 series, their correlation and actual number of degrees of freedom. (b) Composite analysis of the
853 CCA time series for the 8 phases of the MJO as defined by the RMM indices. Only days
854 characterized by an MJO amplitude larger than one standard deviation are considered. Asterisks
855 denote 95% significant anomalies according to a *t*-test. (c) Cross-spectral analysis between the
856 CCA time series and RMM1 index. All analyses are carried out on normalized data for the NDJF
857 1979-2012 period, with other months padded with zeros. Thick lines: squared coherence. Dashed
858 lines: 95% level according to 1000 random time series obtained as permutations of the original
859 time series, and having the same lag-1 serial correlation. Thin lines: phase relationship in degrees.

860

861 **Figure 6** Lead-lag composite analysis of daily OLR (shadings, $W m^{-2}$), horizontal wind
862 (vectors, $m s^{-1}$) at 200hPa (left-hand panels) and 850hPa (right-hand panels), and opposite phases
863 (>1 standard deviation minus <-1 standard deviation) of the AM time series shown in Fig. 5. Only
864 95% significant differences according to a two-tailed t -test (for OLR) and t^2 -test (for the wind) are
865 displayed. The t^2 -test, also known as Hotelling test, is the multivariate generalization of the t -test.
866

867 **Figure 7** As Fig. 6 but based on the AF time series of Fig. 5.
868

869 **Figure 8** Composite analysis of OLR (shadings, $W m^{-2}$), horizontal wind (vectors, $m s^{-1}$) at
870 200hPa (a) and 850hPa (b) for the 8 phases of the MJO as defined by the RMM indices.
871 Significance is tested as for Fig. 6. Only days characterized by an MJO amplitude larger than one
872 standard deviation are considered in the analysis.
873

874 **Figure 9** As Fig. 5a but for 10-day highpass filtered (synoptic-scale) OLR. No lag
875 (synchronous OLR fields) is applied between the two regions.
876

877 **Figure 10** As Fig. 6 but based on the AM time series of Fig. 9.
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879 **Figure 11** As Fig. 6 but based on the AF time series of Fig. 9.
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881 **Figure 12** As Fig. 6 but extracting the synchronous opposite phases of both AM and AF time
882 series of Fig. 9 (i.e., “both positive” minus “both negative” events).
883

884 **Figure 13** Scale interactions between the interannual, intraseasonal and synoptic modes of
885 variability and co-variability. (a) Interannual vs. synoptic in the AM region. Box-and-whisker
886 representation of the seasonal variance of the AM time series for the synoptic scale, during El
887 Niño, neutral ENSO and La Niña years. The boxes have lines at the lower quartile, median and
888 upper quartile values. The whiskers are lines extending from each end of the box to show the range
889 of the data. Outliers (outside of 1.5 inter-quartile range) appear as plus signs. (b) As (a) for the AF
890 domain. (c, d) As (a,b) but for interannual vs. intraseasonal timescales. (e) AF vs. AM,
891 intraseasonal scale. Cross-spectral analysis between the two time series of Fig. 6. (f) As (e) for the
892 synoptic scale and the time series of Fig. 9. (g) Intraseasonal vs. synoptic in AM. (h) As (g) for
893 AF.
894

895 **Figure S1** Principal component analysis of OLR anomalies over the "South American" sector,
896 period NDJF 1979-2012. The first three modes are significant according to a scree-test. All spatial
897 patterns are correlation maps with the principal component time series. Dashed curves show the
898 95% significance bound according to a Bravais-Pearson test. The variance explained by each mode
899 is labeled in the figure.
900

901 **Figure S2** As Fig. S1 over the "Southern African" sector, with five modes retained as
902 significant.

903

904

905 **Table Captions**

906

907 **Table 1** Contingency table of the negative ($[-\infty -1]$), neutral ($[-1 1]$) and positive ($[1 +\infty]$)
908 scores between the American ("AM") and African ("AF") time series at the synoptic scale. The
909 first line indicates the number of occurrences and the second line corresponding percentages.

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TABLE

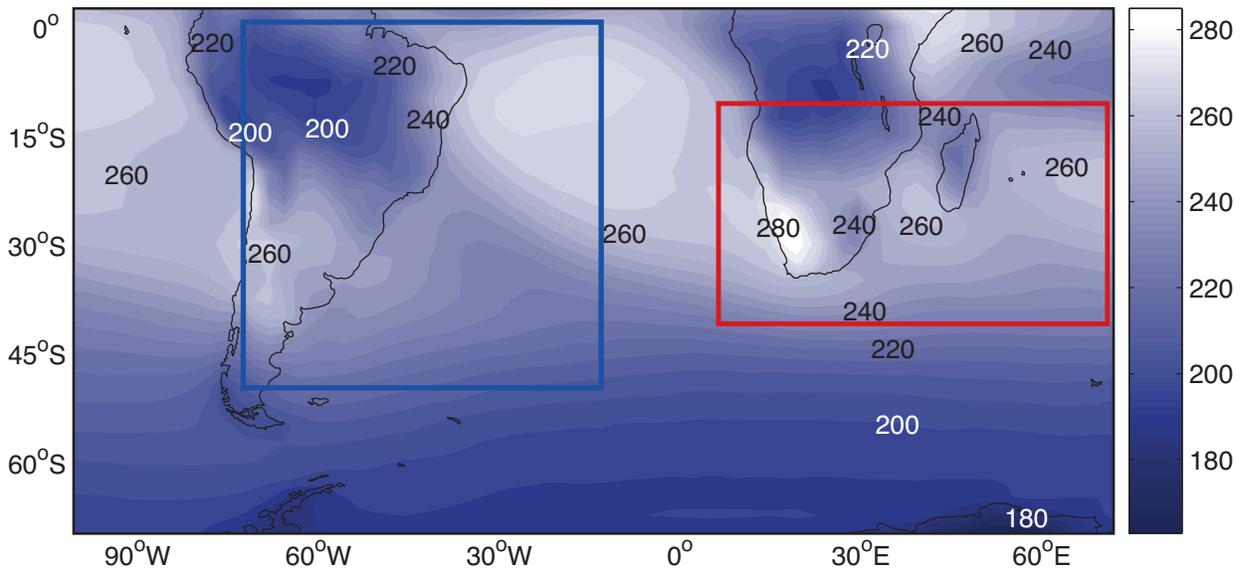
	AM < -1	-1 ≤ AM ≤ +1	AM > +1	Total
AF < -1	143 3.6%	409 10.4%	49 1.2%	601 15.2%
-1 ≤ AF ≤ +1	406 10.3%	1962 49.5%	398 10.0%	2766 69.8%
AF > +1	59 1.5%	369 9.3%	165 4.2%	593 15.0%
Total	608 15.4%	2740 69.2%	612 15.4%	3960 100%

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Table 1 Contingency table of the negative ($[-\infty -1]$), neutral ($[-1 1]$) and positive ($[1 +\infty]$) scores between the American (“AM”) and African (“AF”) time series at the synoptic scale. The first line indicates the number of occurrences and the second line corresponding percentages.

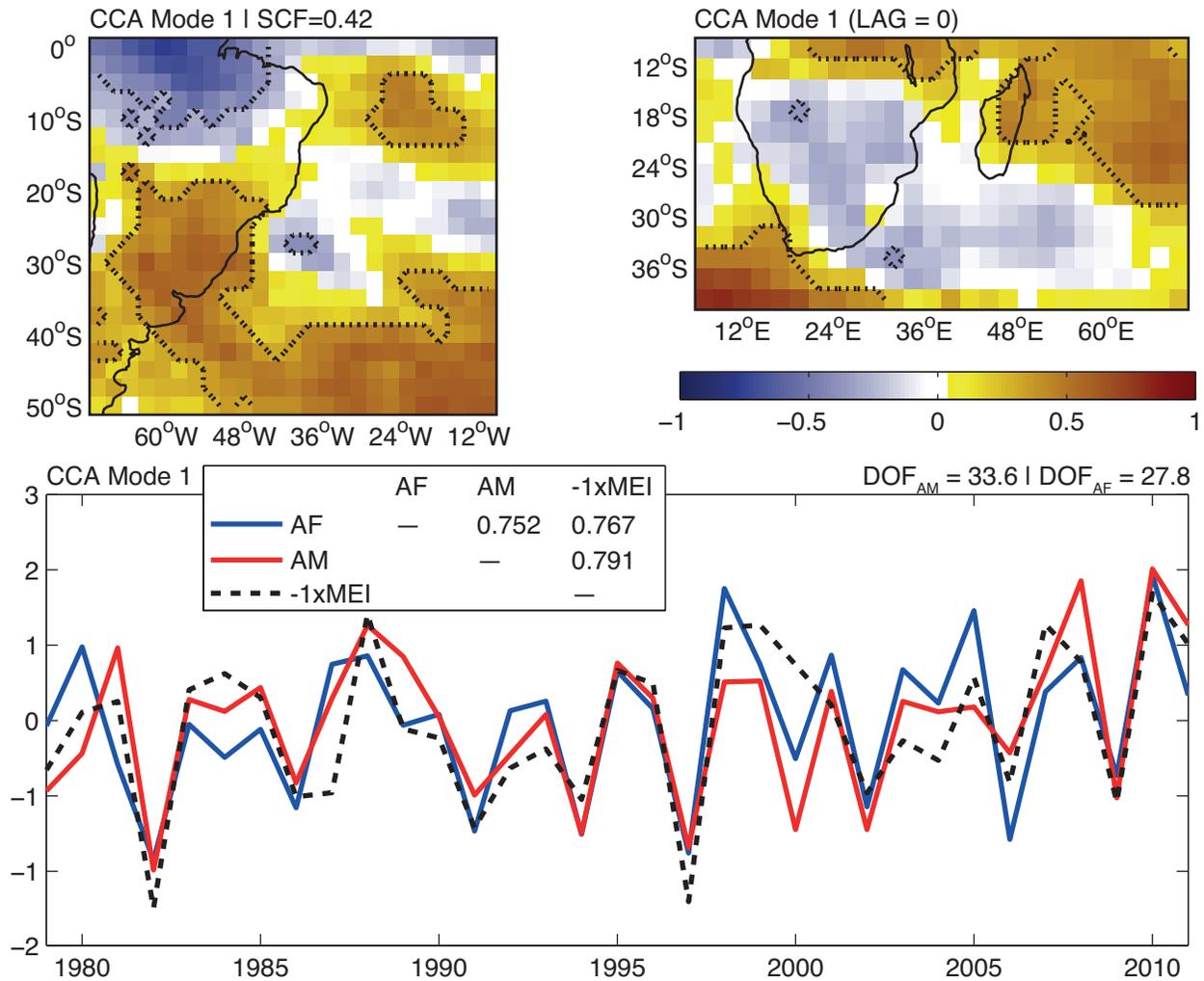
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FIGURES



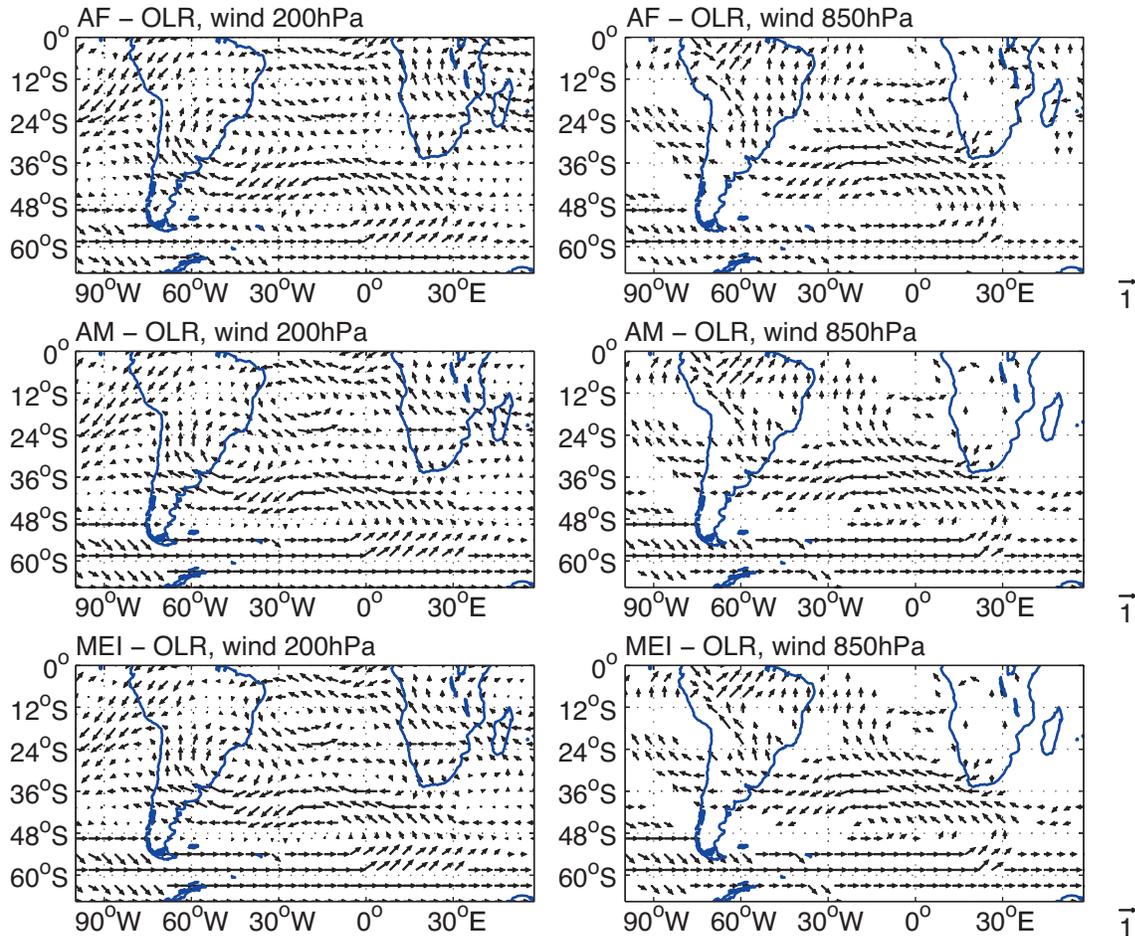
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926 **Figure 1** Study domain for the "South American" sector (in blue: 50°S-0°, 70°W-10°W) and
927 "Southern African" sector (in red: 40°S-10°S, 7.5°E-70°E), as well as the large region
928 encompassing both domains. Shadings represent the austral summer (November through
929 February) seasonal mean OLR field ($W m^{-2}$).



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932 **Figure 2** Canonical correlation analysis of seasonal mean OLR co-variability at the
 933 interannual timescale between the "South American" and "Southern African" sectors, period NDJF
 934 1979-2012. Upper panels: first mode of co-variability, displayed through heterogeneous
 935 correlation maps. Dashed curves show the 95% significance bound according to a Bravais-Pearson
 936 test. The squared coherence fraction (SCF) is labeled in the figure. Lower panel: associated time
 937 series, represented together with the seasonal mean Multivariate ENSO Index (MEI, multiplied by
 938 -1 for readability) over the same period. The correlation matrix between these time series and their
 939 actual number of degrees of freedom (considering possible serial auto-correlation) are indicated in
 940 the figure.



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943 **Figure 3** Interannual correlations between the seasonal mean and horizontal wind at 200hPa
944 (left-hand panels) and 850hPa (right-hand panels), and the three time series shown in Fig. 2. Only
945 95% significant correlations according to a Bravais-Pearson test are displayed.

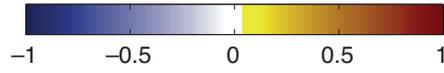
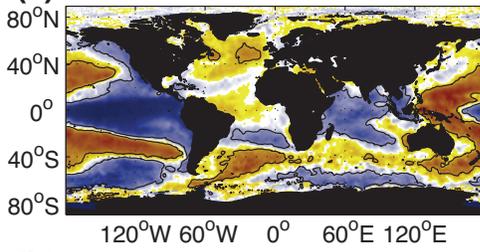
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954 **Figure 4** (a) Interannual correlations between the seasonal mean SST and synchronous MEI,
955 period NDJF 1979-2012. Black contours show 95% significant correlations according to a Bravais-
956 Pearson test. (b, c) As (a) but for the AM and AF time series of Fig. 2, respectively. (d, e) As (b,c)
957 but after removing linearly the influence of the synchronous MEI. (f-j) As (a-e) but correlations
958 with the seasonal mean OLR field over the domain shown in Fig. 1.

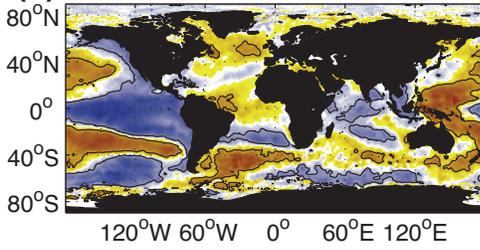
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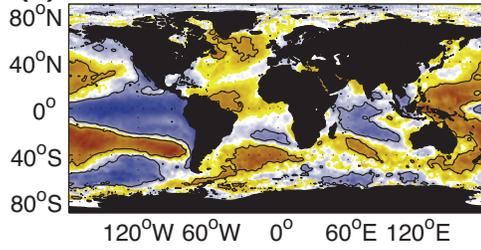
(a) $-1 \times \text{MEI} - \text{SST}$



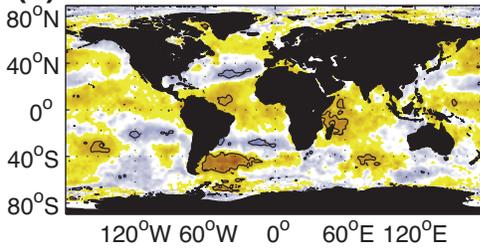
(b) $\text{AM} - \text{SST}$



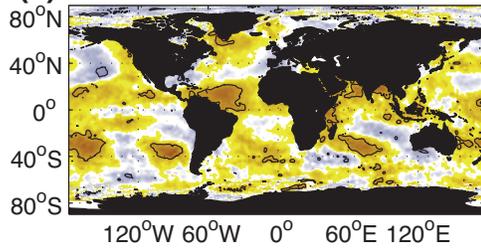
(c) $\text{AF} - \text{SST}$



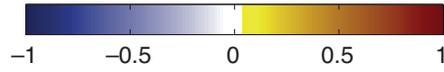
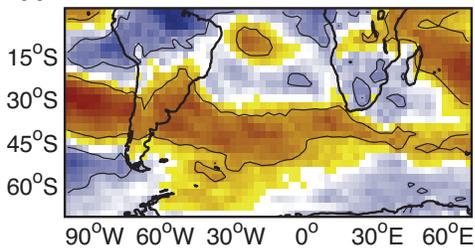
(d) $\text{AM} - \text{SST} \setminus \text{MEI}$



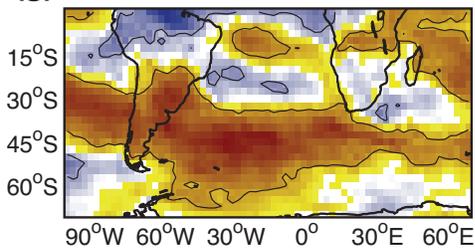
(e) $\text{AF} - \text{SST} \setminus \text{MEI}$



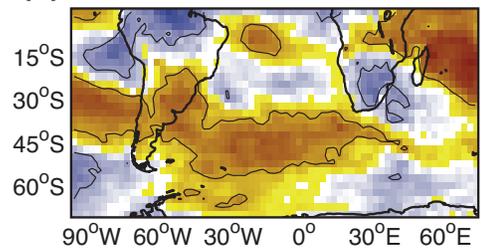
(f) $-1 \times \text{MEI} - \text{OLR}$



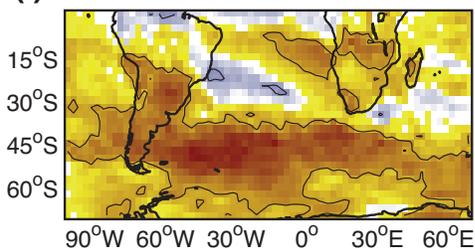
(g) $\text{AM} - \text{OLR}$



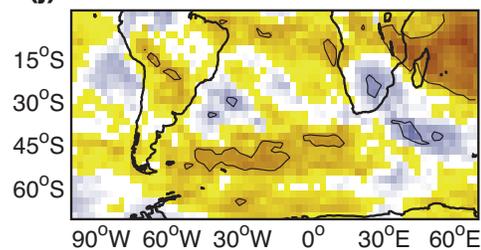
(h) $\text{AF} - \text{OLR}$

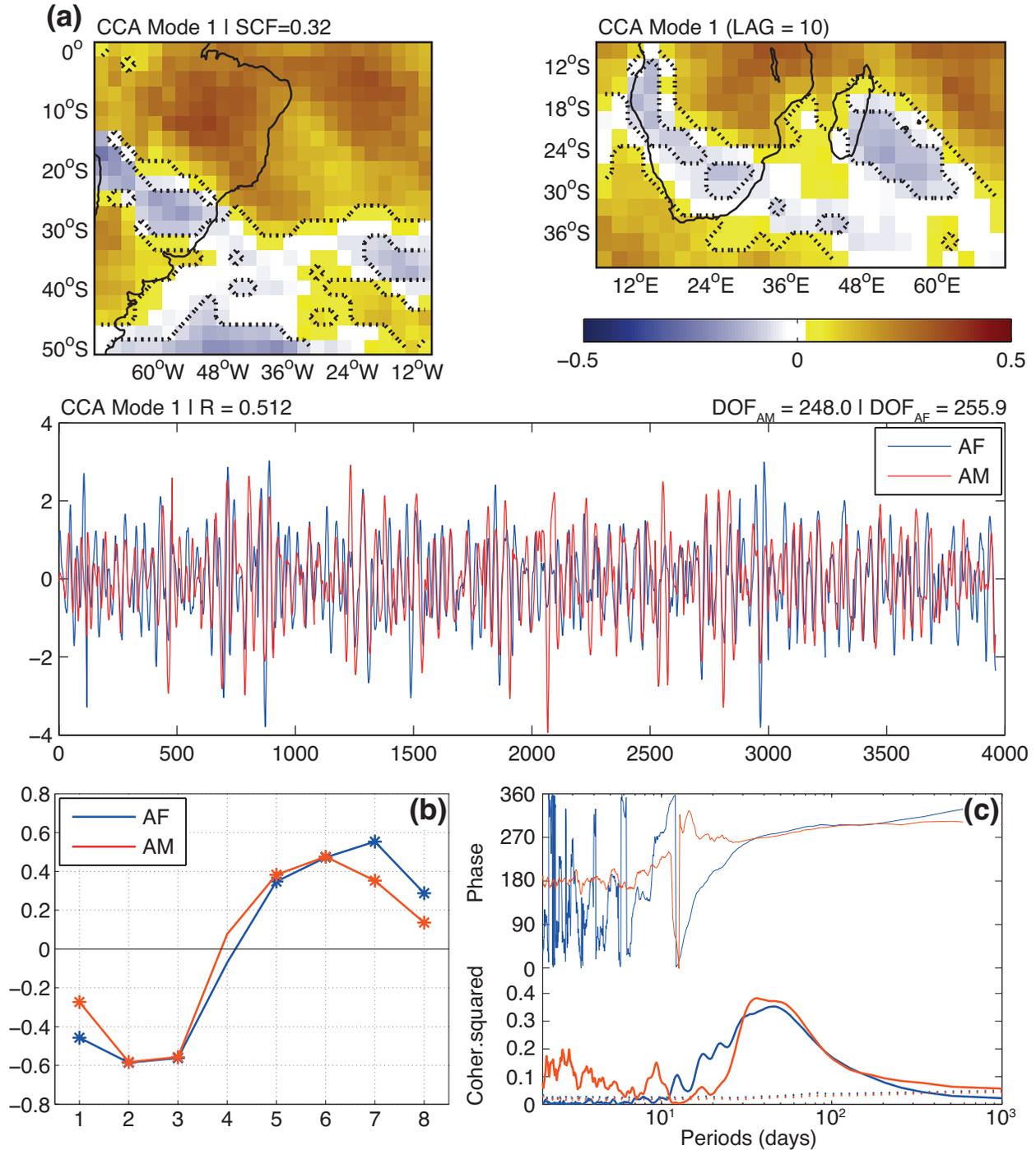


(i) $\text{AM} - \text{OLR} \setminus \text{MEI}$



(j) $\text{AF} - \text{OLR} \setminus \text{MEI}$





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963 **Figure 5** (a) Canonical correlation analysis of 25-75-day bandpass filtered (intraseasonal)
964 OLR co-variability between the "South American" and "Southern African" sectors, period NDJF
965 1979-2012. Upper panels: as Fig. 2, upper panels. A lag of 10 days is here applied between the
966 two regions (South America leads Southern Africa by 10 days). Central panel: associated time
967 series, their correlation and actual number of degrees of freedom. (b) Composite analysis of the
968 CCA time series for the 8 phases of the MJO as defined by the RMM indices. Only days

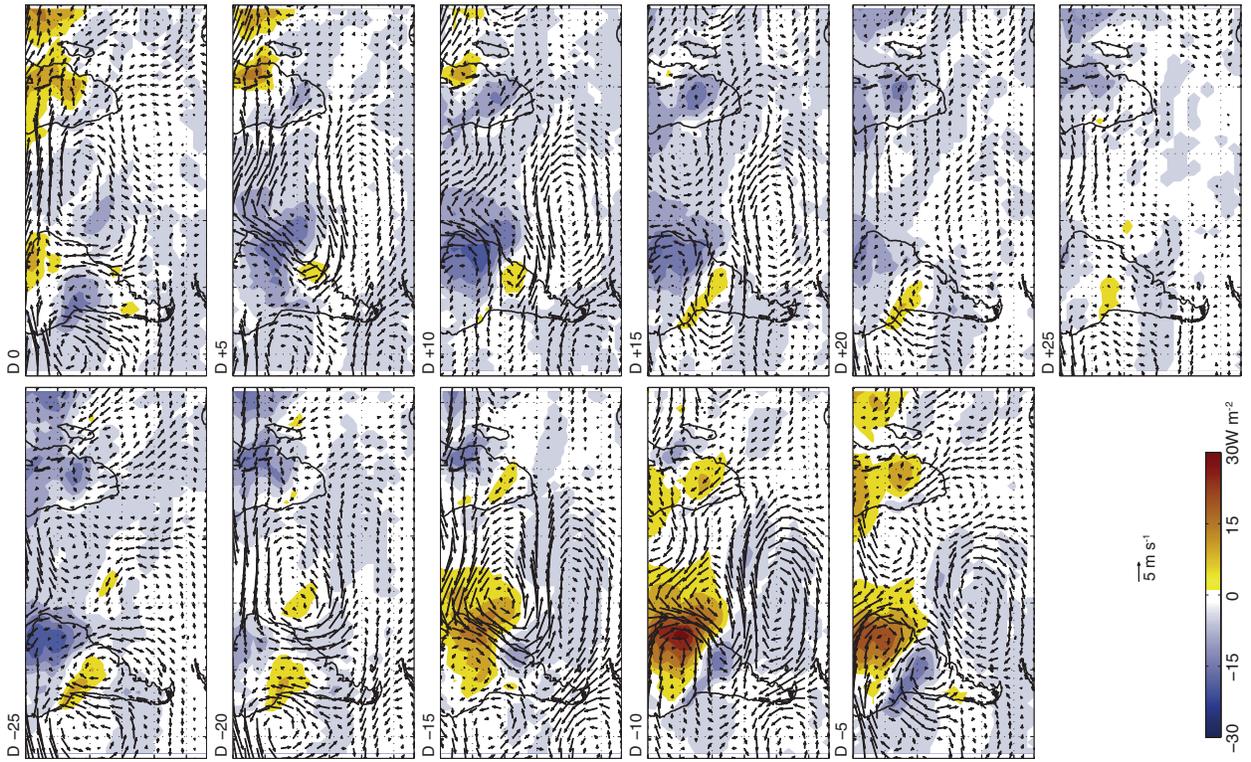
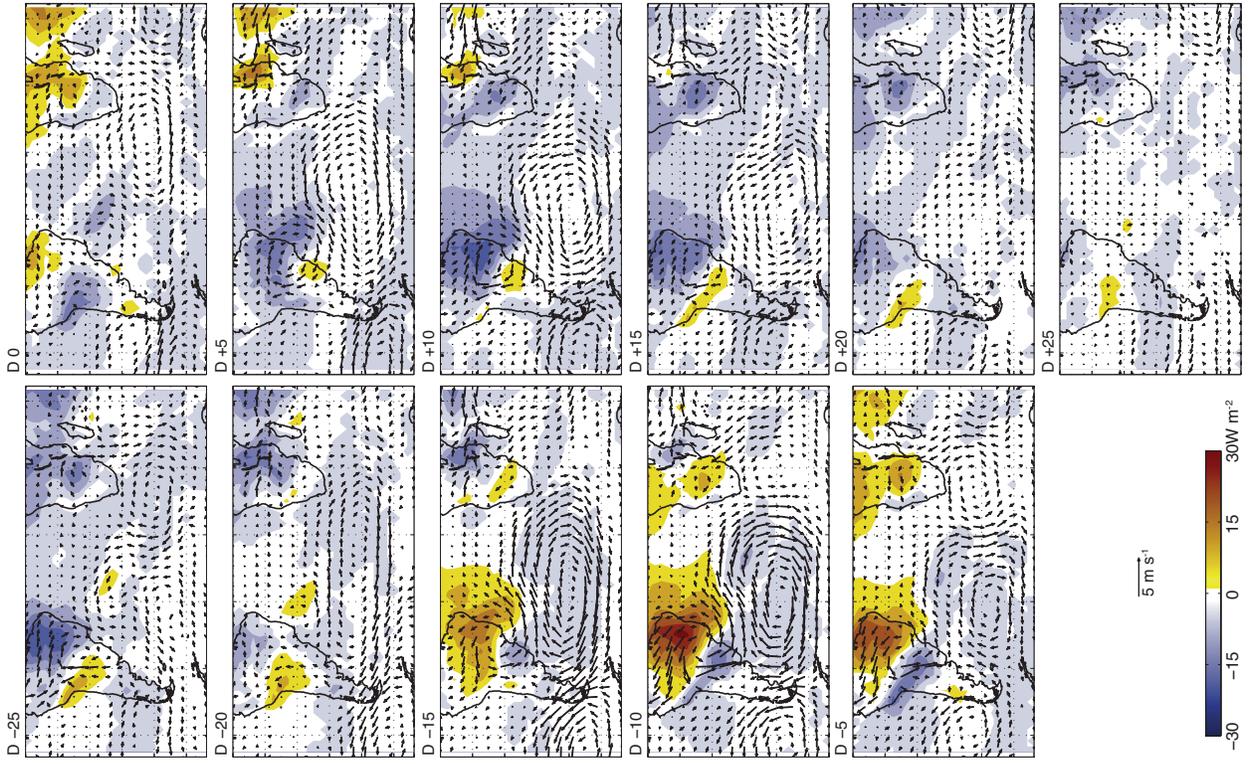
969 characterized by an MJO amplitude larger than one standard deviation are considered. Asterisks
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971 CCA time series and RMM1 index. All analyses are carried out on normalized data for the NDJF
972 1979-2012 period, with other months padded with zeros. Thick lines: squared coherence. Dashed
973 lines: 95% level according to 1000 random time series obtained as permutations of the original
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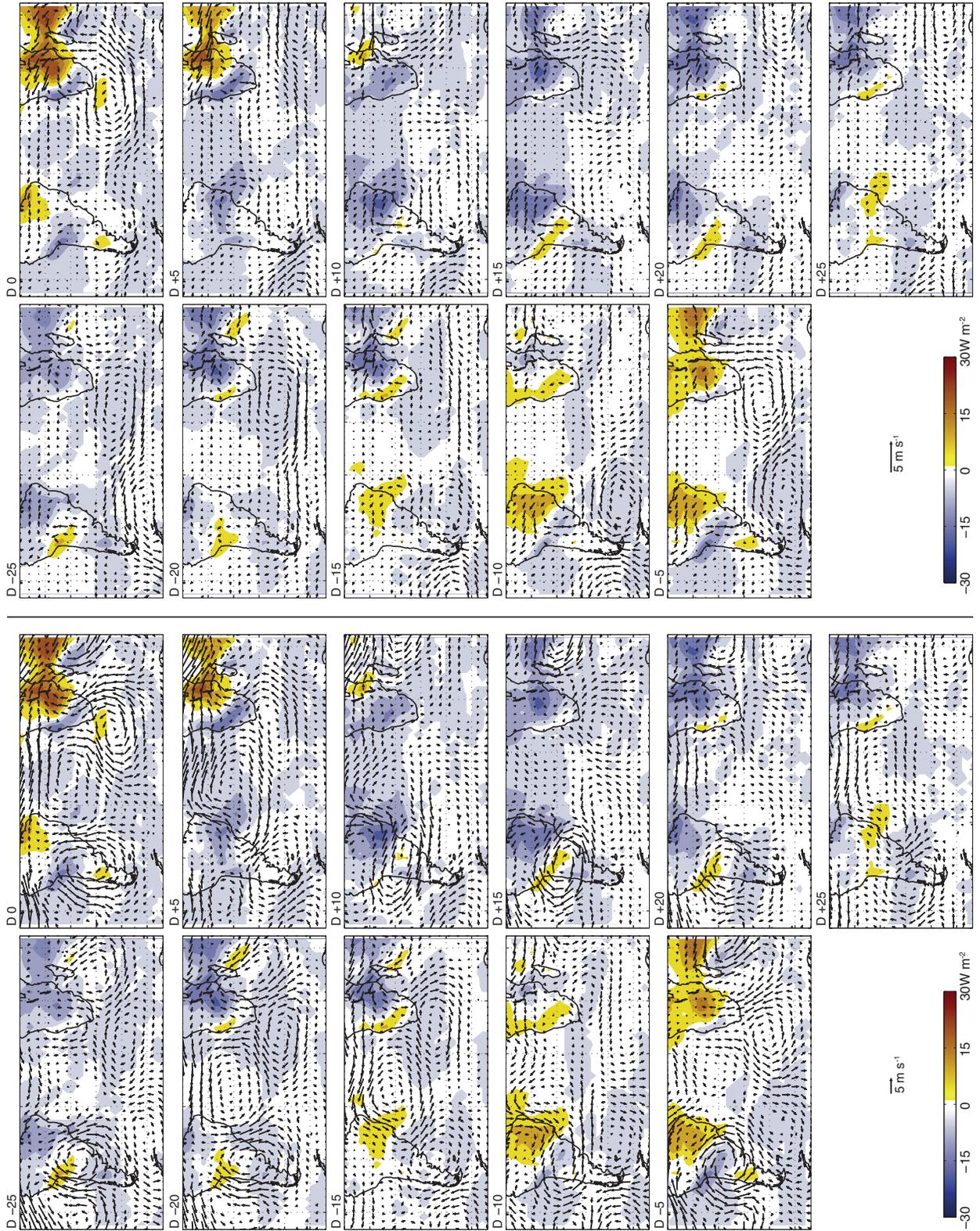
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1002 (vectors, $m s^{-1}$) at 200hPa (left-hand panels) and 850hPa (right-hand panels), and opposite phases
1003 (>1 standard deviation minus <-1 standard deviation) of the AM time series shown in Fig. 5. Only
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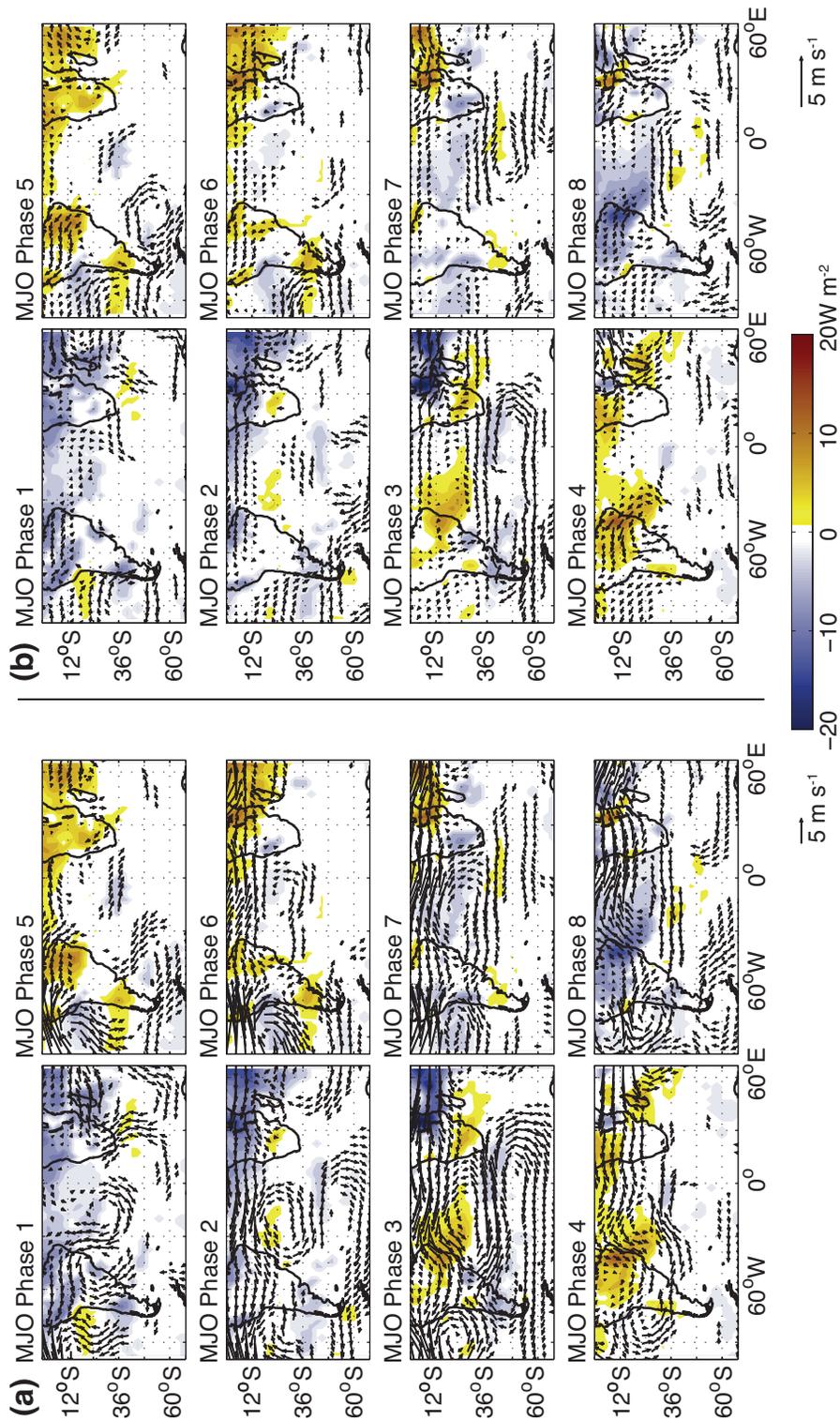


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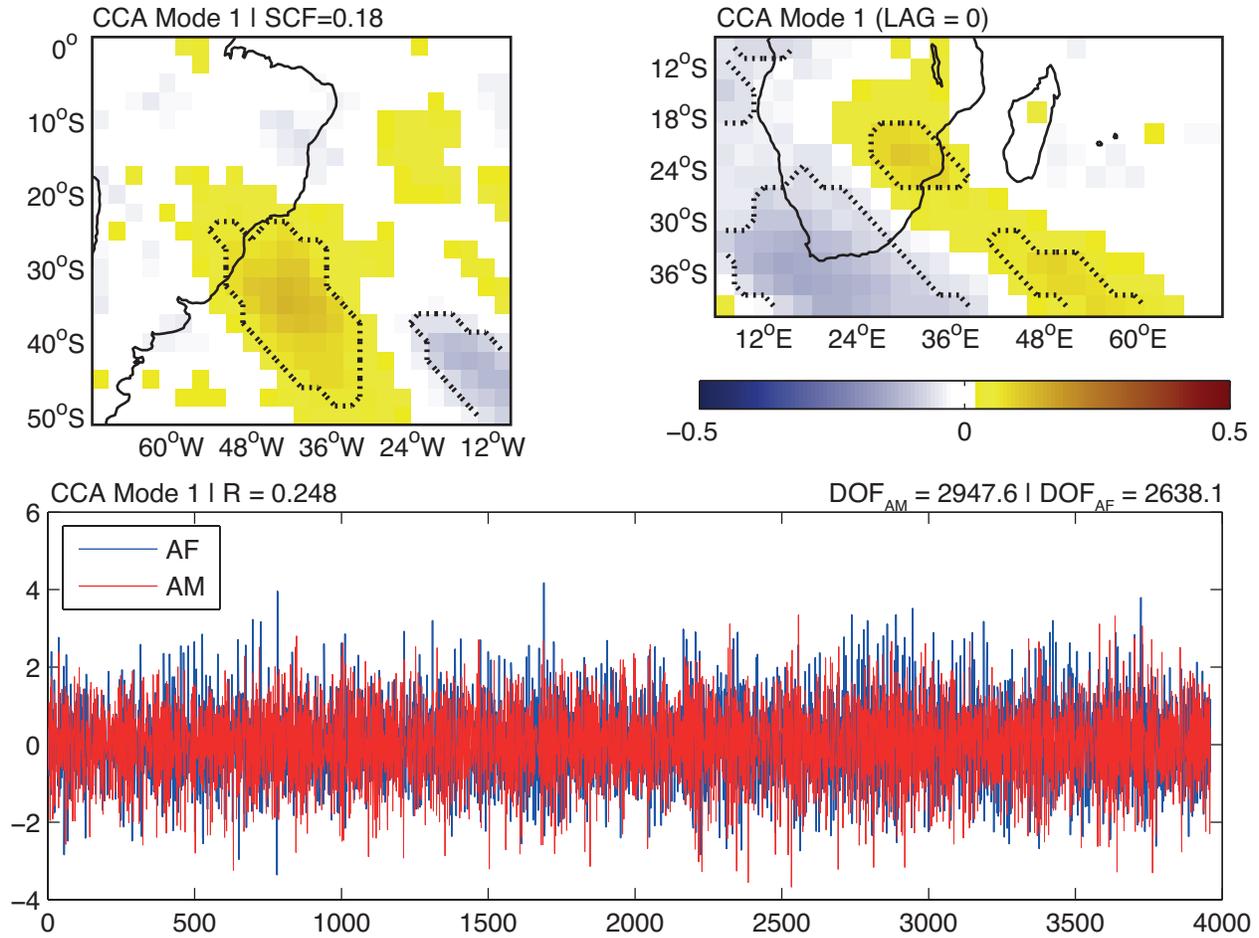


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Figure 7 As Fig. 6 but based on the AF time series of Fig. 5.

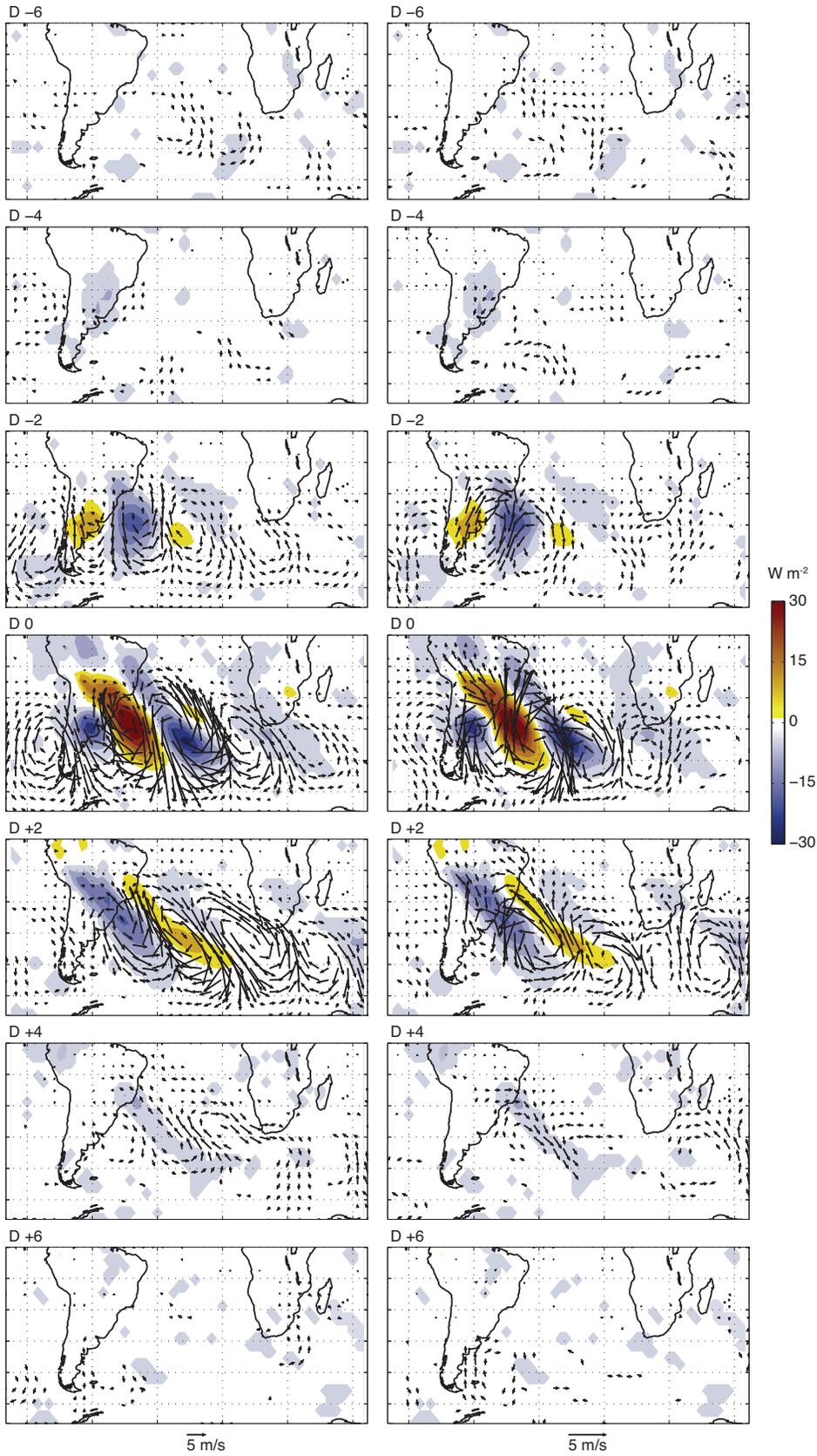


1013
 1014 **Figure 8** Composite analysis of OLR (shadings, $W m^{-2}$), horizontal wind (vectors, $m s^{-1}$) at
 1015 200hPa (a) and 850hPa (b) for the 8 phases of the MJO as defined by the RMM indices.
 1016 Significance is tested as for Fig. 6. Only days characterized by an MJO amplitude larger than one
 1017 standard deviation are considered in the analysis.



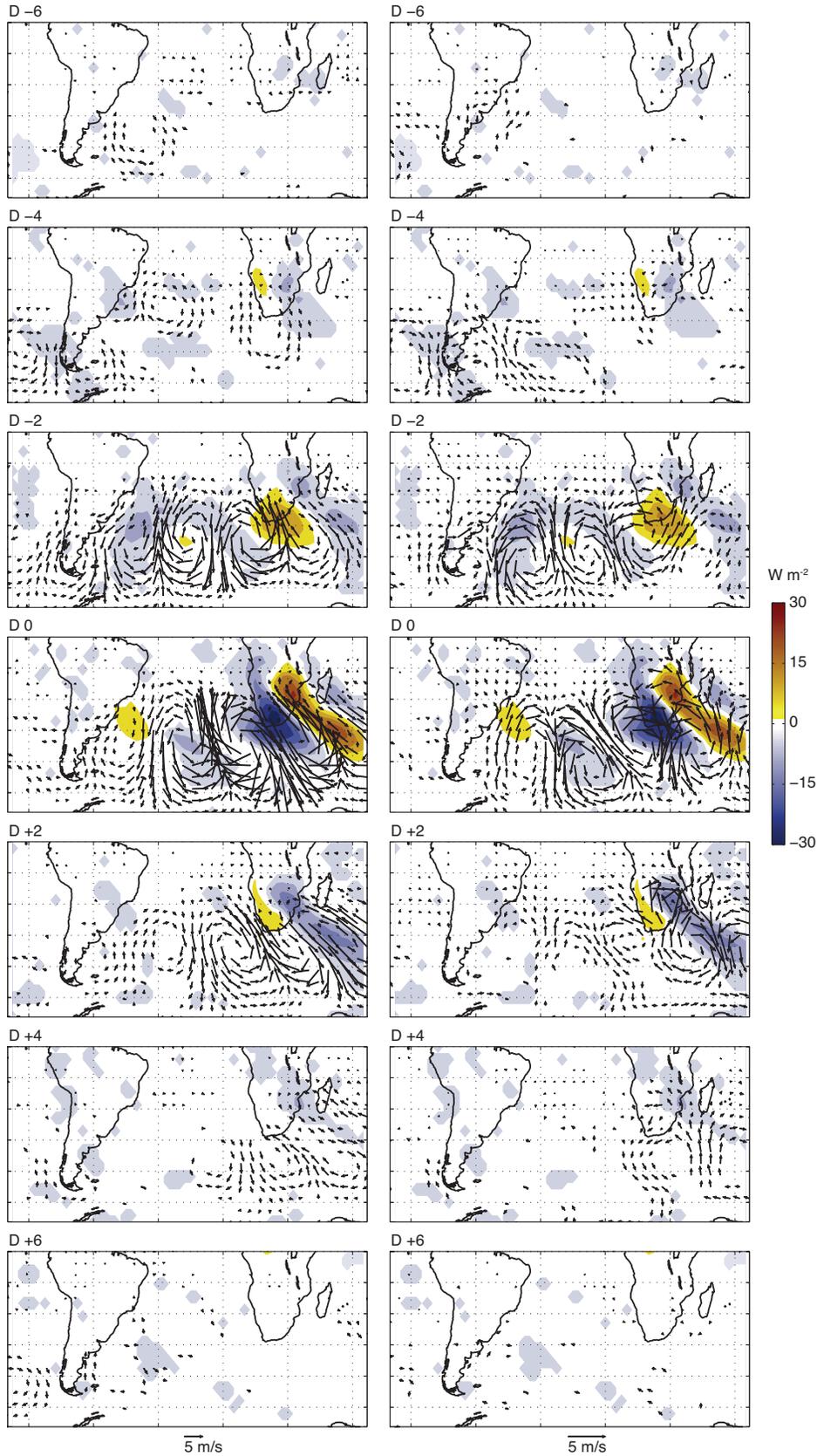
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Figure 9 As Fig. 5a but for 10-day highpass filtered (synoptic-scale) OLR. No lag (synchronous OLR fields) is applied between the two regions.



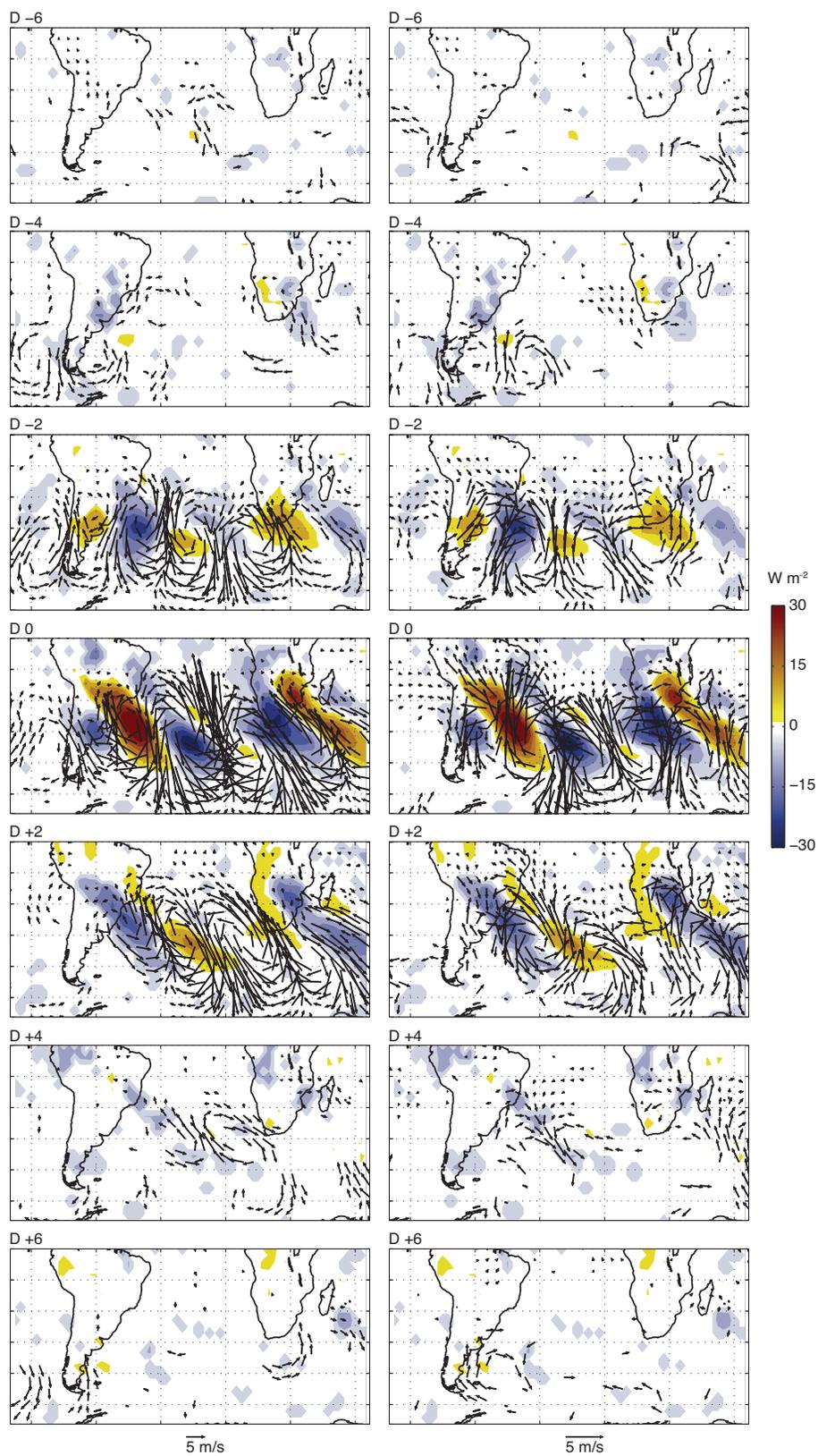
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Figure 10 As Fig. 6 but based on the AM time series of Fig. 9.



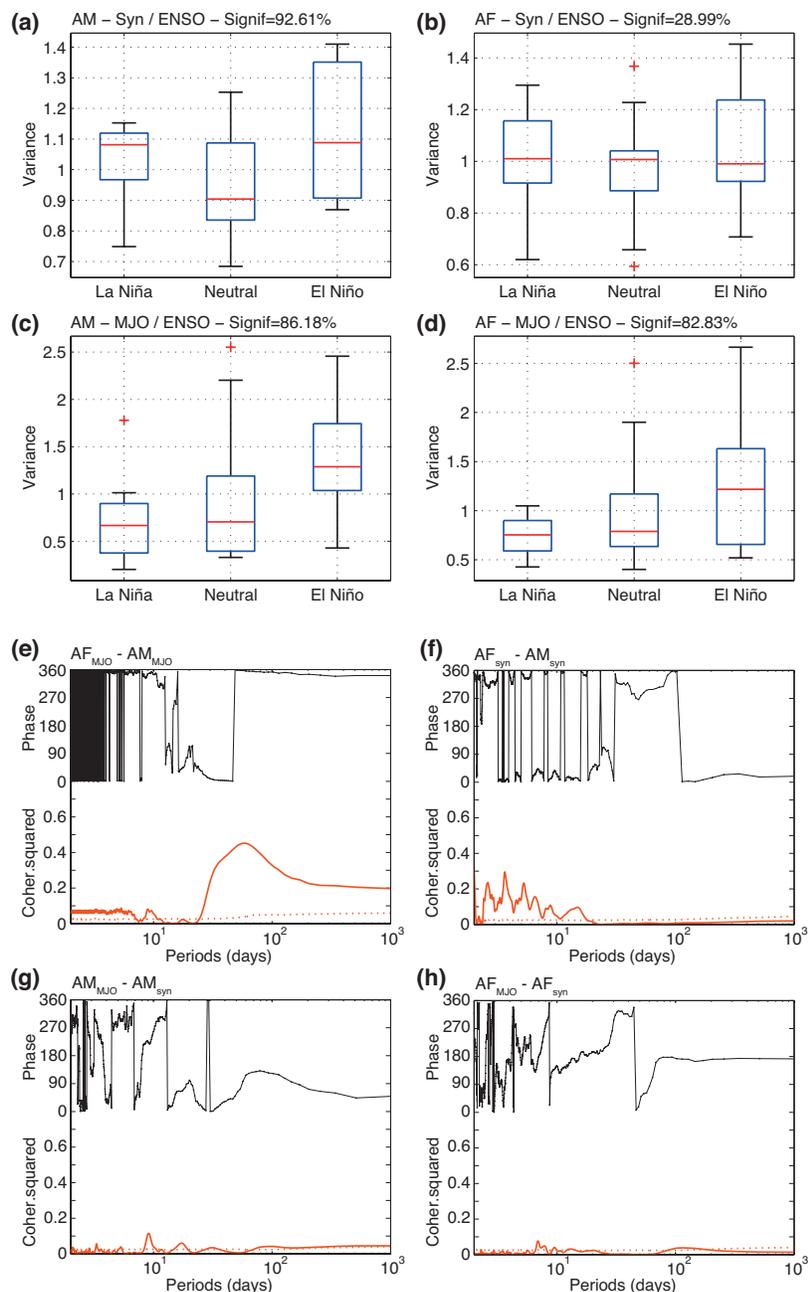
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Figure 11 As Fig. 6 but based on the AF time series of Fig. 9.

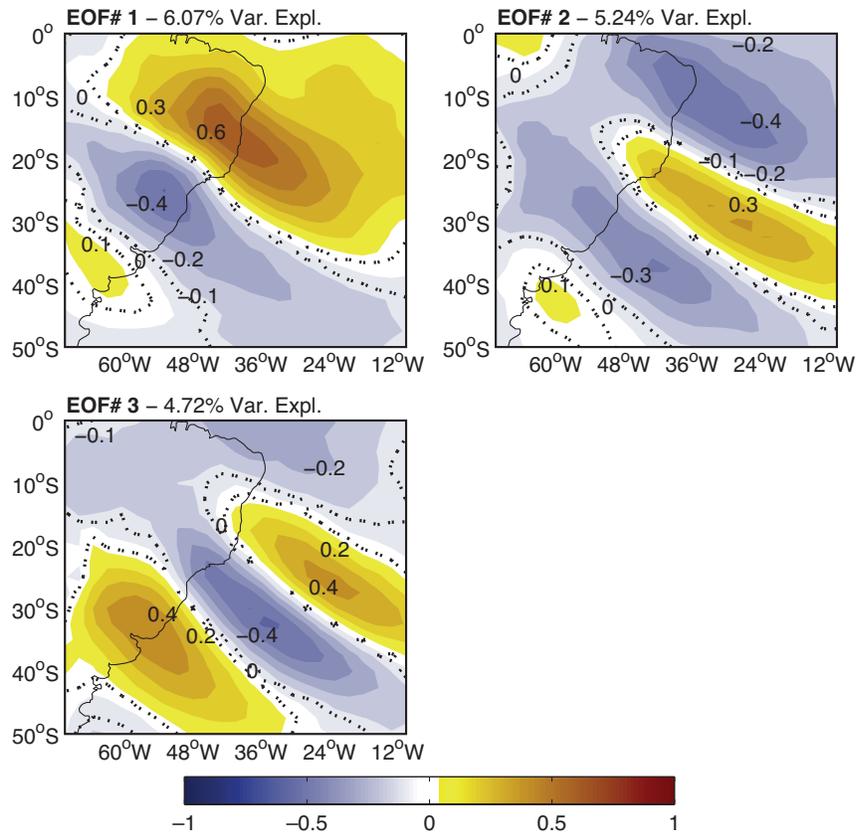


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Figure 12 As Fig. 6 but extracting the synchronous opposite phases of both AM and AF time series of Fig. 9 (i.e., “both positive” minus “both negative” events).

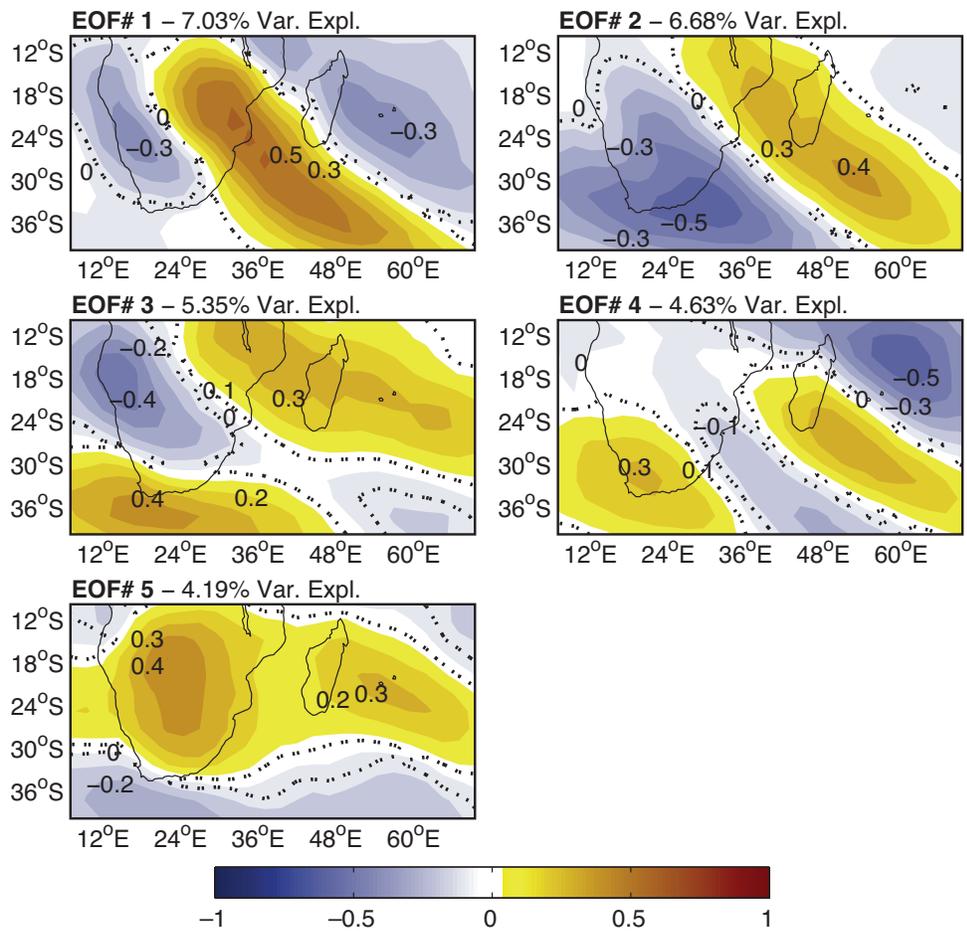


1029
 1030 **Figure 13** Scale interactions between the interannual, intraseasonal and synoptic modes of
 1031 variability and co-variability. (a) Interannual vs. synoptic in the AM region. Box-and-whisker
 1032 representation of the seasonal variance of the AM time series for the synoptic scale, during El
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 1034 upper quartile values. The whiskers are lines extending from each end of the box to show the range
 1035 of the data. Outliers (outside of 1.5 inter-quartile range) appear as plus signs. (b) As (a) for the AF
 1036 domain. (c, d) As (a,b) but for interannual vs. intraseasonal timescales. (e) AF vs. AM,
 1037 intraseasonal scale. Cross-spectral analysis between the two time series of Fig. 6. (f) As (e) for the
 1038 synoptic scale and the time series of Fig. 9. (g) Intraseasonal vs. synoptic in AM. (h) As (g) for
 1039 AF.



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Figure S1 Principal component analysis of OLR anomalies over the "South American" sector, period NDJF 1979-2012. The first three modes are significant according to a scree-test. All spatial patterns are correlation maps with the principal component time series. Dashed curves show the 95% significance bound according to a Bravais-Pearson test. The variance explained by each mode is labeled in the figure.



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Figure S2 As Fig. S1 over the "Southern African" sector, with five modes retained as significant.