ADVANCED SCHOOL AND WORKSHOP ON AMERICAN MONSOONS: PROGRESS AND FUTURE PLANS

SYNOPTIC PATTERNS ASSOCIATED WITH WET SEASON ONSET IN THE TROPICAL HIGH ANDES OF SOUTHERN PERU AND BOLIVIA

TANIA K. ITA VARGAS

Appalachian STATE UNIVERSITY

Thesis committee: Dr. L. Baker Perry, Dr. Magaret M. Sugg, Dr. Isabel Moreno

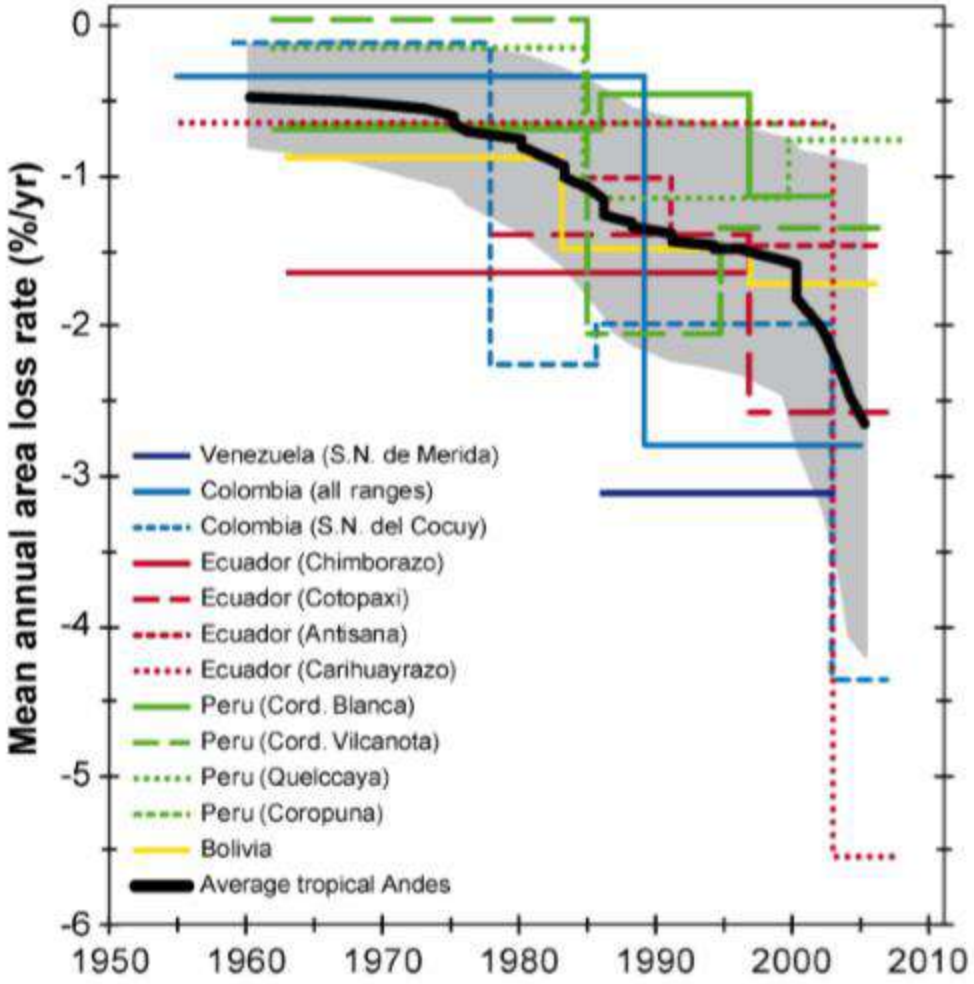
Christian Barreto Schuler, Dr. Anton Seimon, Joe Jonaitis, Heather Guy

SENAMHI – Perú, SENAMHI – Bolivia, DECADE Project

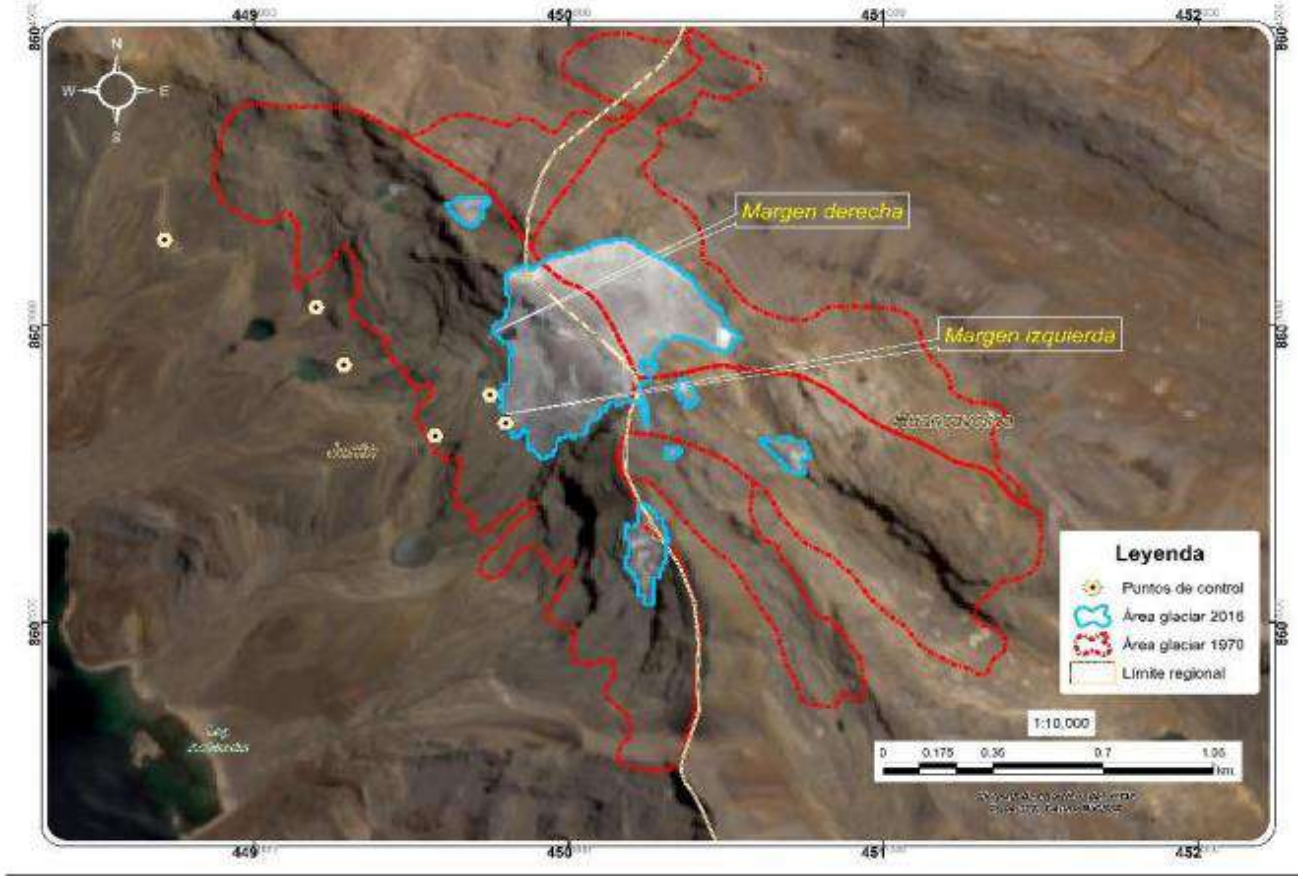
NSF-GRANT AGS-1347179

Precipitation plays an important role in the outer tropical Andes

Exacerbating glacier retreat

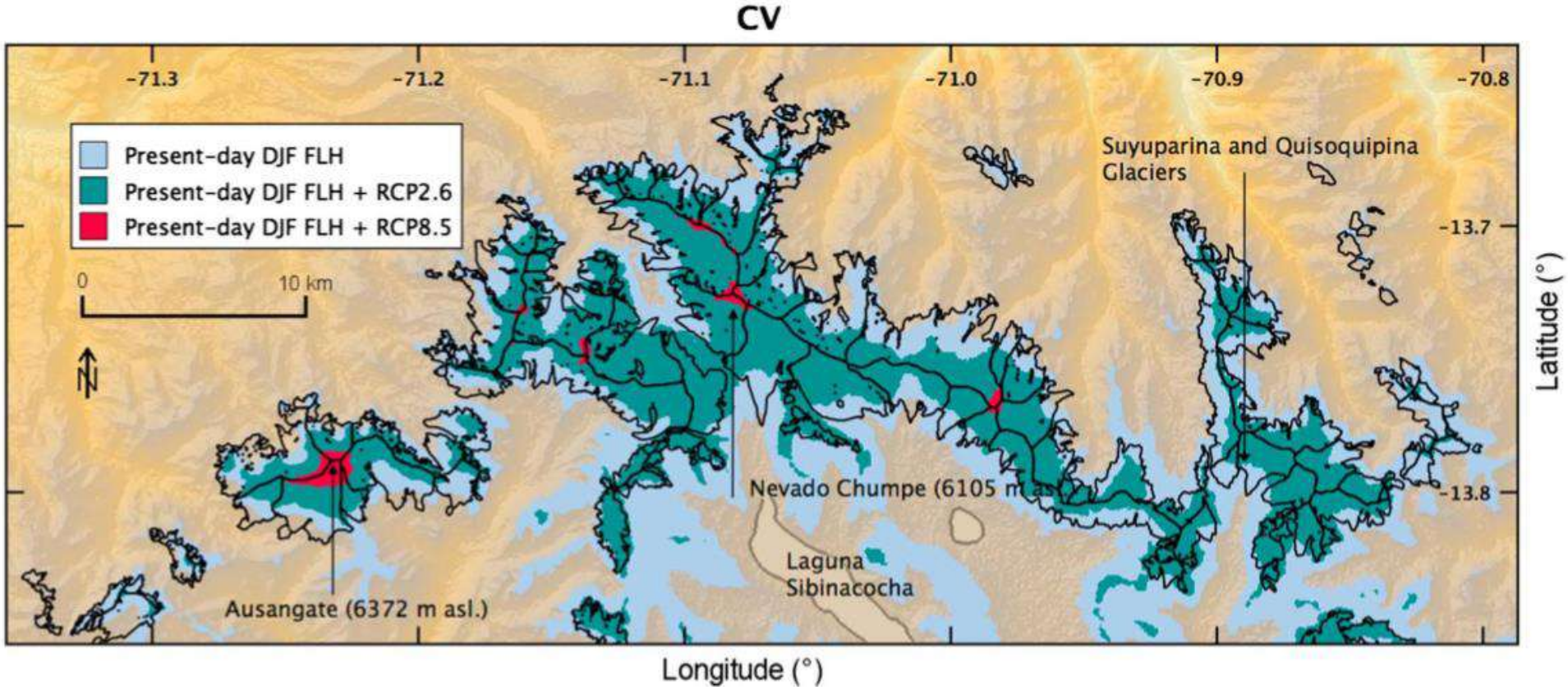


Rabatel et al. 2013



CONDORAY GLACIER – HUANCAVELICA- PERU
INAIGEM 2016

Future of Andean Glaciers

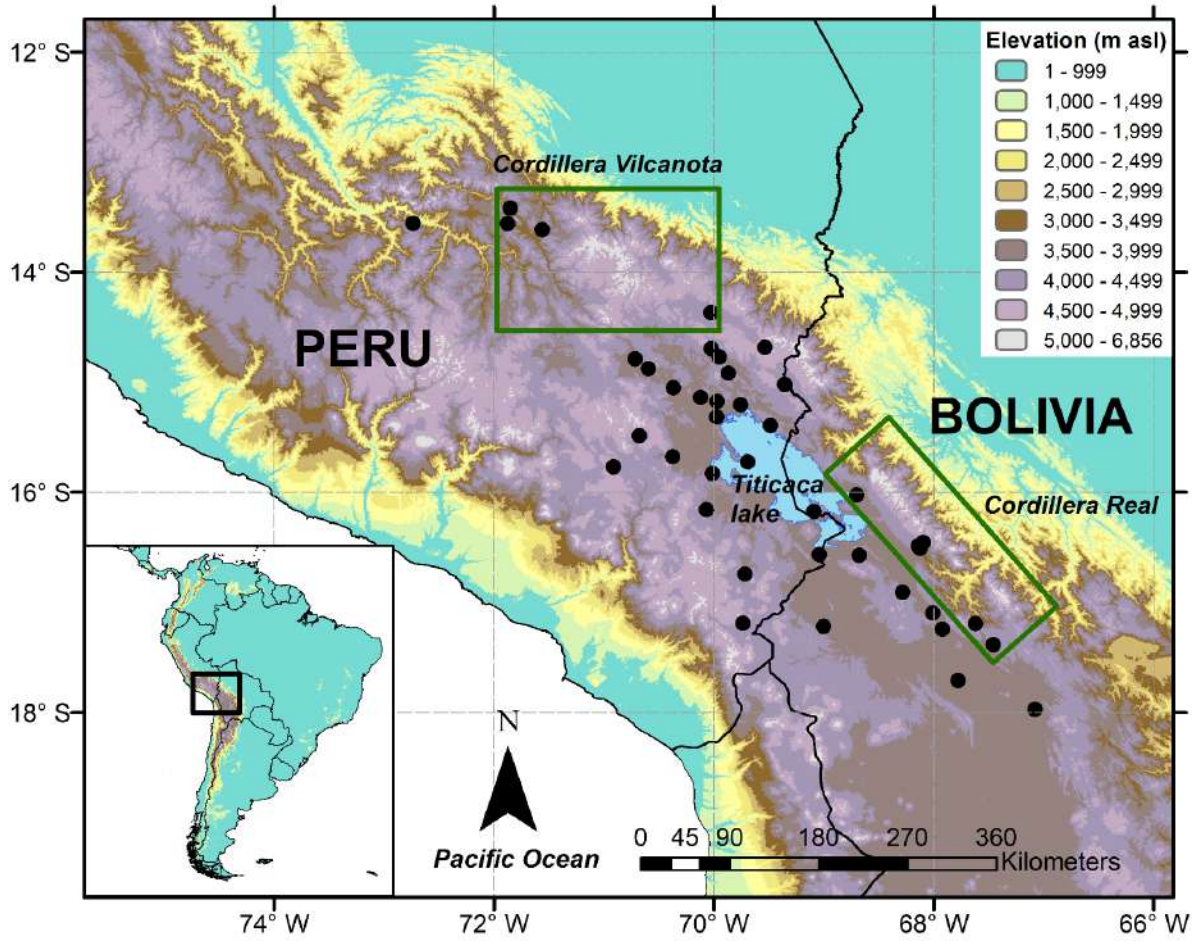


Schauwecker et al. 2017

Research focus: Wet Season Onset

1. Identify the wet season timing in the study area.
2. Identify the synoptic patterns associated with wet season onset.
3. Assess early and late wet season onset cases.
4. Determine trends in the wet season onset.

Study area



- Cordillera Vilcanota (Peru).
- Cordillera Real (Bolivia).
- More than 60% of all tropical glaciers between 12 and 16°S (Rabatel et al. 2013).

1. Identification of the wet season timing

Rain gauge data

- Daily observations (43 weather stations)
- >2500 masl
- Jul 1979 to Jun 2017
- >90% of complete information
- Currently recording
- SENAMHI-Peru, SENAMHI-Bolivia, DECADE Project

Terrain elevation model

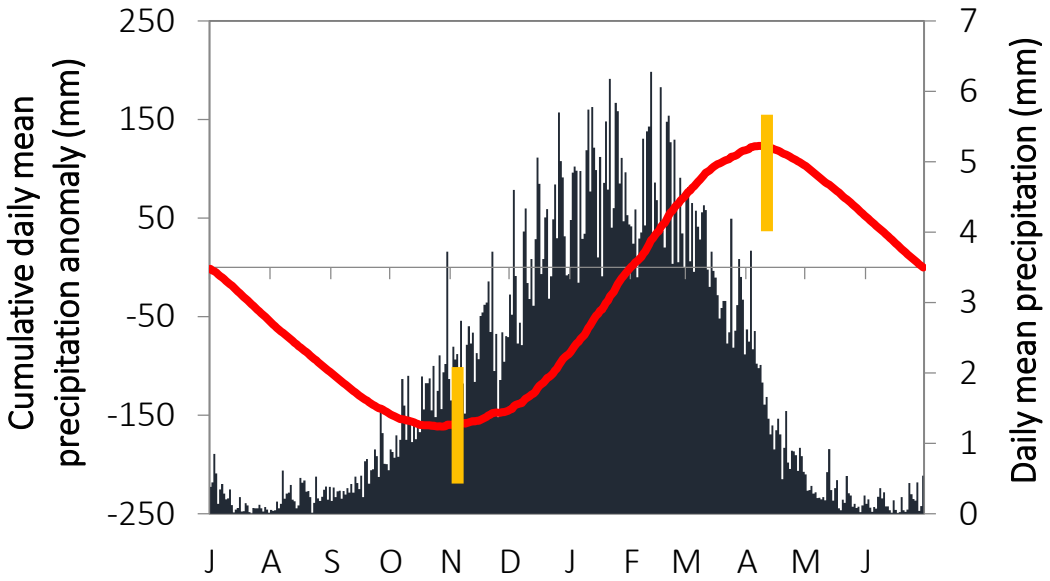
- Mean product of the Global Multi-resolution Terrain Elevation Data 2010 (GMTED2010)
- Spatial resolution of 0.0020833333 decimal degrees

Method: Liebmann et al. 2001; Liebmann et al. 2007; Dunning et al. 2016

Cumulative daily mean precip. anomaly was calculated $C(d)$

$$C(d) = \sum_{i\,=\,1Jul}^{d} Q_i - \bar{Q}$$

Q_i: climatological mean precip. for the day *i*
$\bar{Q}$: climatological mean precip. based on all days for the 38 years

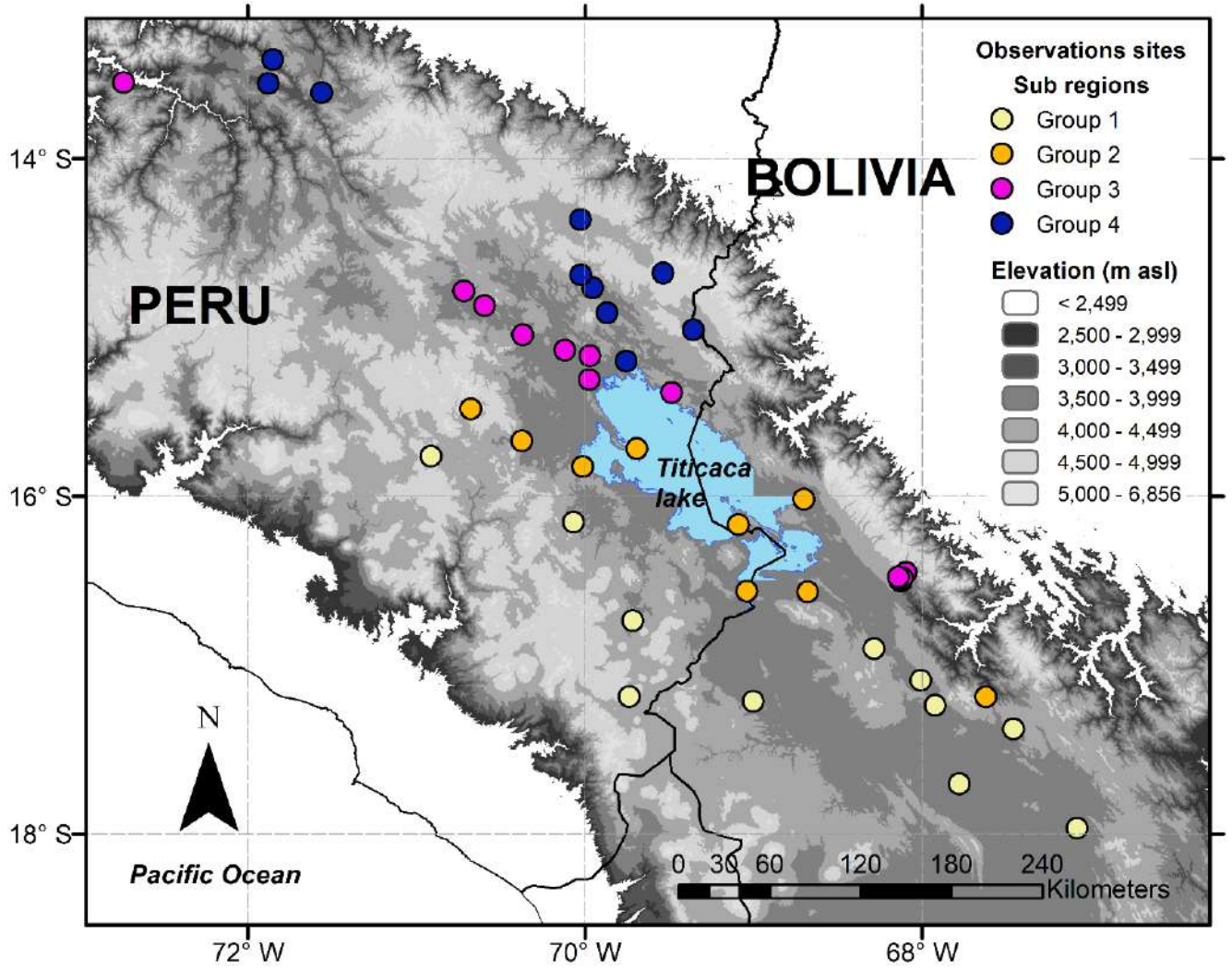


Spatial relationship

Correlation matrix perform following Pearson method (95 % confidence level) among climatological wet season timing (onset, end, and duration) and geographic and topographic characteristic of each particular weather stations.

	Elevation	Latitude	Longitude	Aspect	Slope	Onset	End	Duration
Elevation	1.00							
Latitude	-0.26	1.00						
Longitude	0.23	**-0.86**	1.00					
Aspect	0.14	-0.06	0.08	1.00				
Slope	-0.26	**0.17**	-0.09	0.20	1.00			
Onset	0.09	**-0.61**	0.27	-0.05	-0.14	1.00		
End	0.17	**0.45**	**-0.46**	-0.15	-0.14	-0.29	1.00	
Duration	-0.04	**0.66**	**-0.36**	0.01	0.09	**-0.97**	**0.51**	1.00

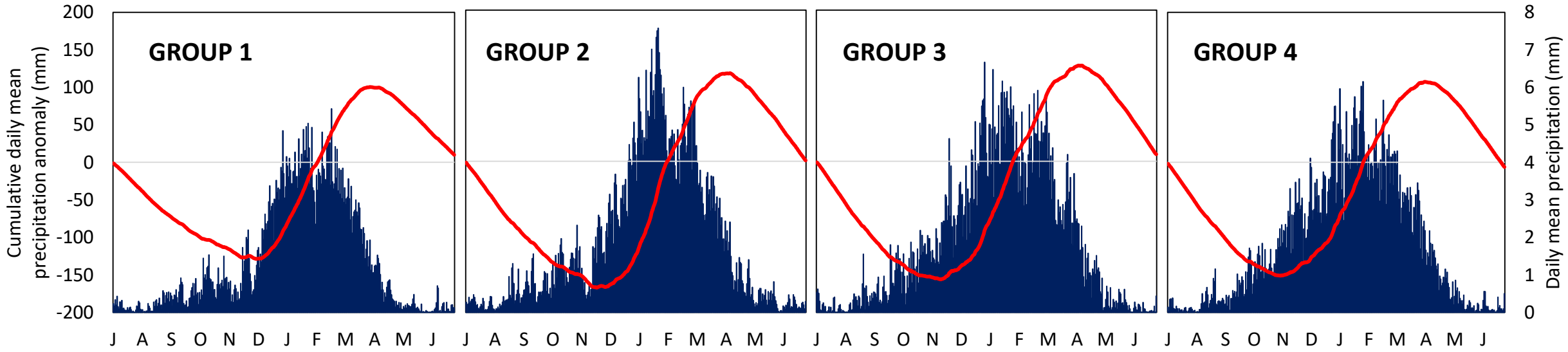
Spatiotemporal variation in the wet season timing



1. NW-SE orientation.
2. Proximity to the equator and to the Amazon basin.
3. Opposite evolution in the wet season onset and end.
4. Significant strong relationship between the wet season onset and the duration.

Character of the wet season timing

Group	Onset	End	Duration (days)	Annual precipitation (mm)	Wet season precipitation (mm)	Percentage of wet season precipitation (%)	Coefficient of variation (%)		
							Onset	End	Duration
1	01/12	27/03	118	502.9	387.2	77.0	14.8	7.1	26.1
2	25/11	30/03	127	688.9	543.4	78.9	17.1	6.6	24.6
3	07/11	03/04	149	700.2	584.0	83.1	19.7	5.3	20.5
4	05/11	04/04	152	663.7	555.9	83.8	16.3	4.8	18.6



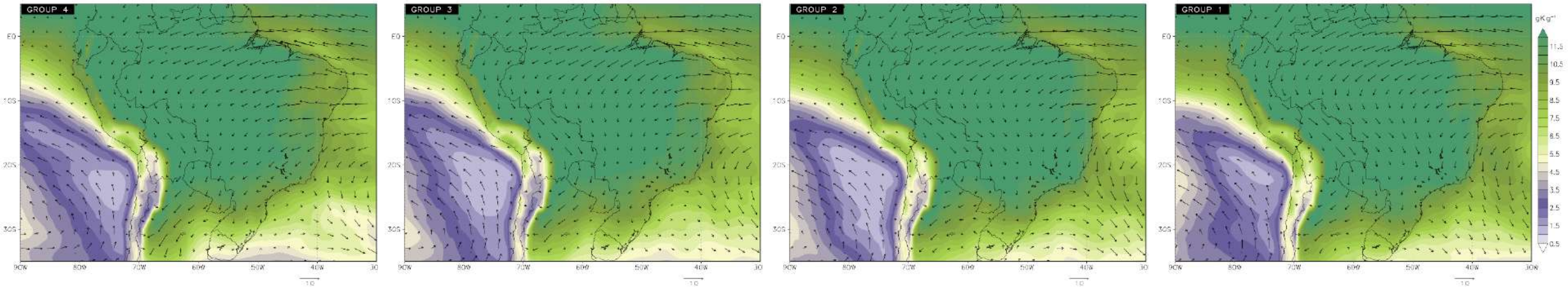
2. Identification of the synoptic patterns associated with wet season onset

ERA-Interim Reanalysis

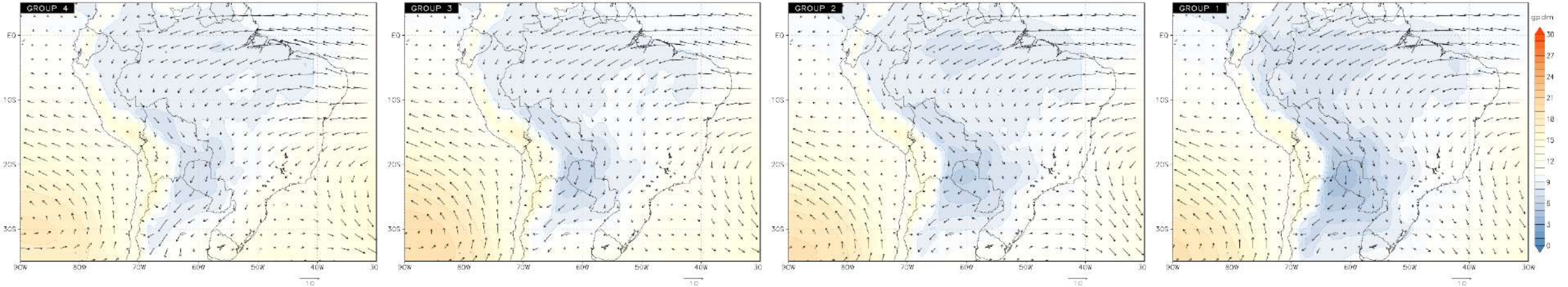
- 0.75° Lat/Lon – 6 hours
- Mandatory levels
- Jul 1979 to Jun 2017
- Variables:
  - u: zonal wind (ms^{-1})
  - v: meridional wind (ms^{-1})
  - q: specific humidity ($kgkg^{-1}$)
  - z: geopotential (m^2s^{-2})

Gradual transition to the summer atmospheric features

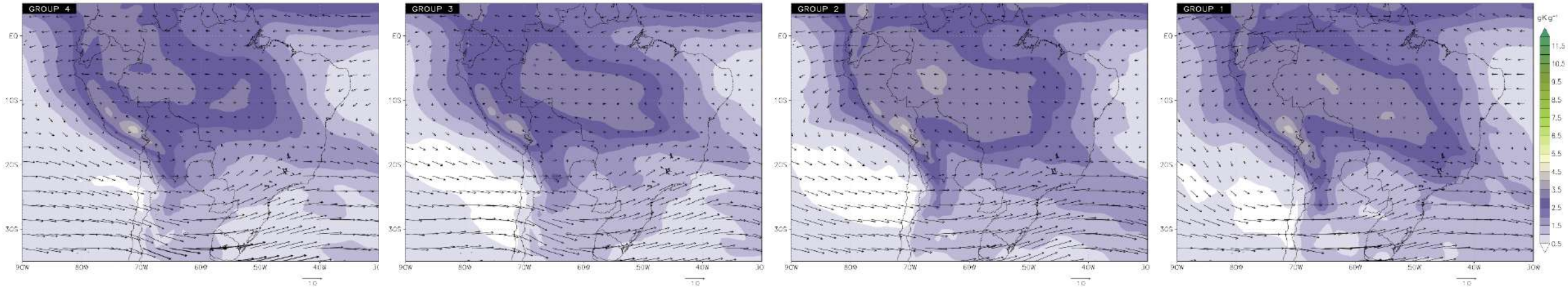
specific humidity (gkg^{-1}) and wind (ms^{-1}) – 850 hPa



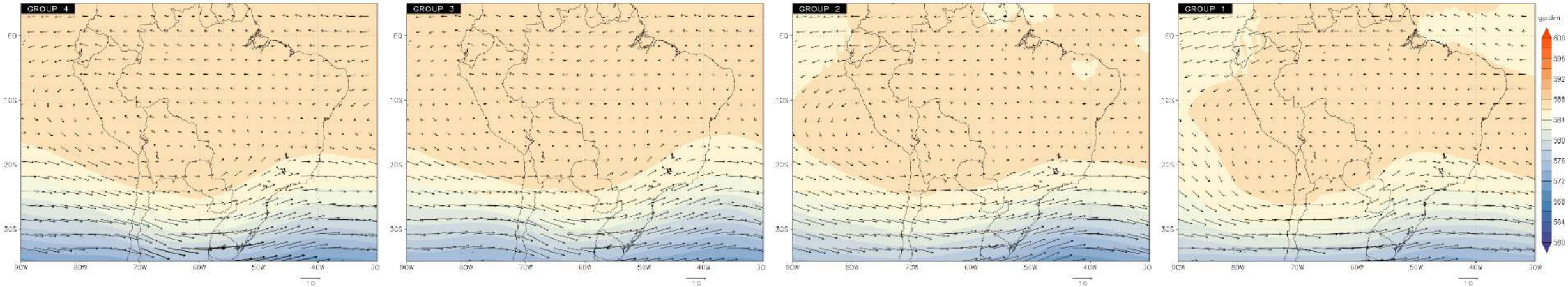
Geopotential height (*gpdm*) – 1000 hPa, wind (ms^{-1}) – 850 hPa



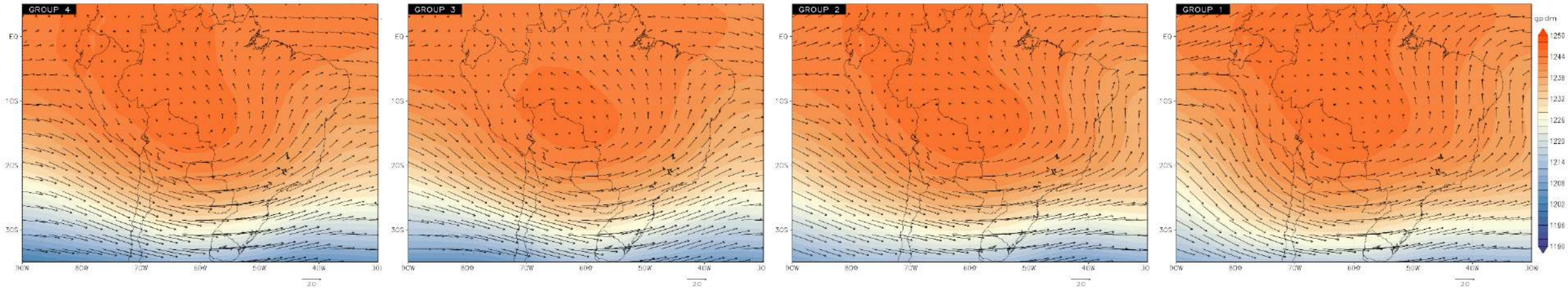
Specific humidity (gkg^{-1}) and wind (ms^{-1}) – 500 hPa



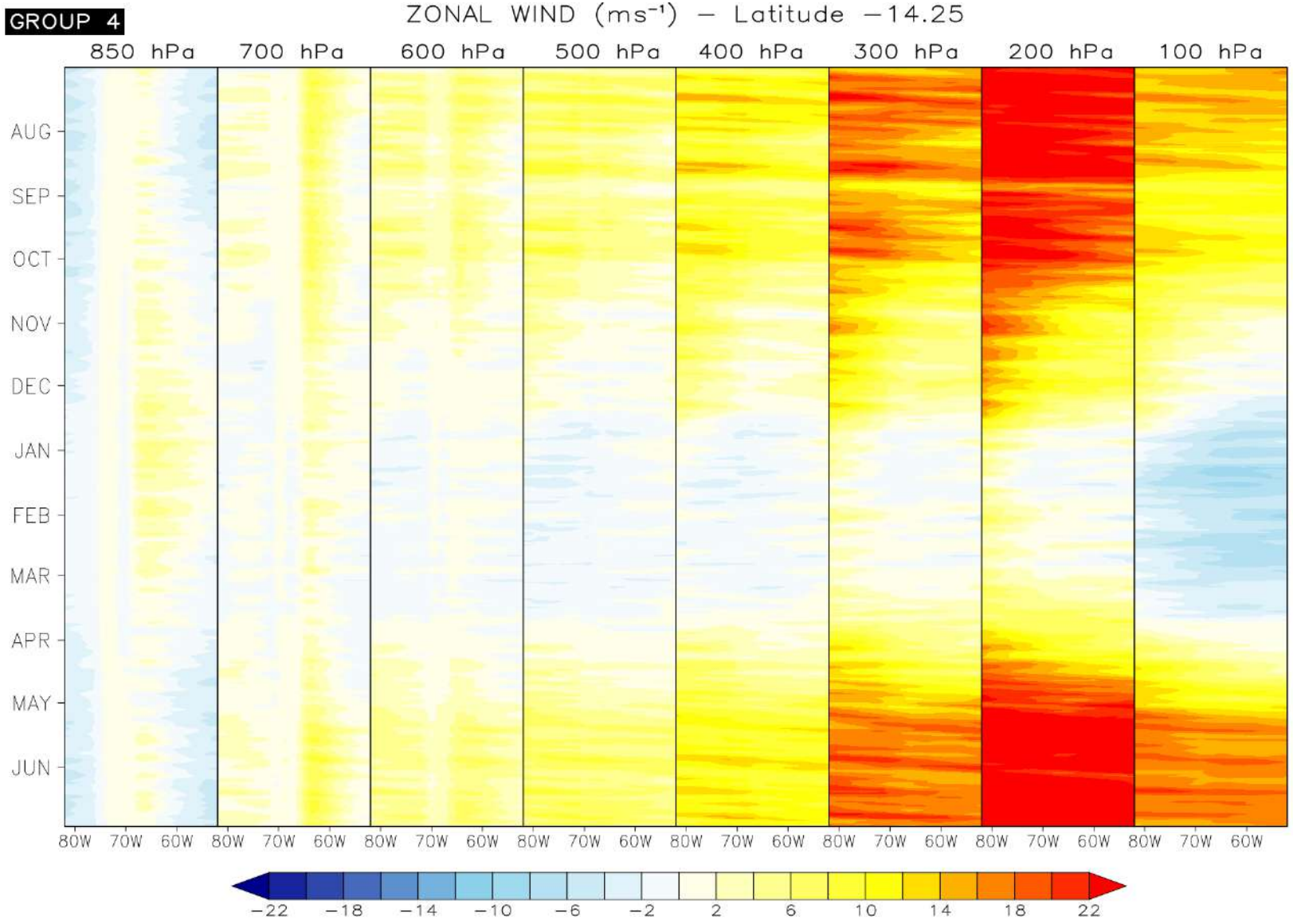
Geopotential height (*gpdm*) and wind (ms^{-1}) 500 hPa

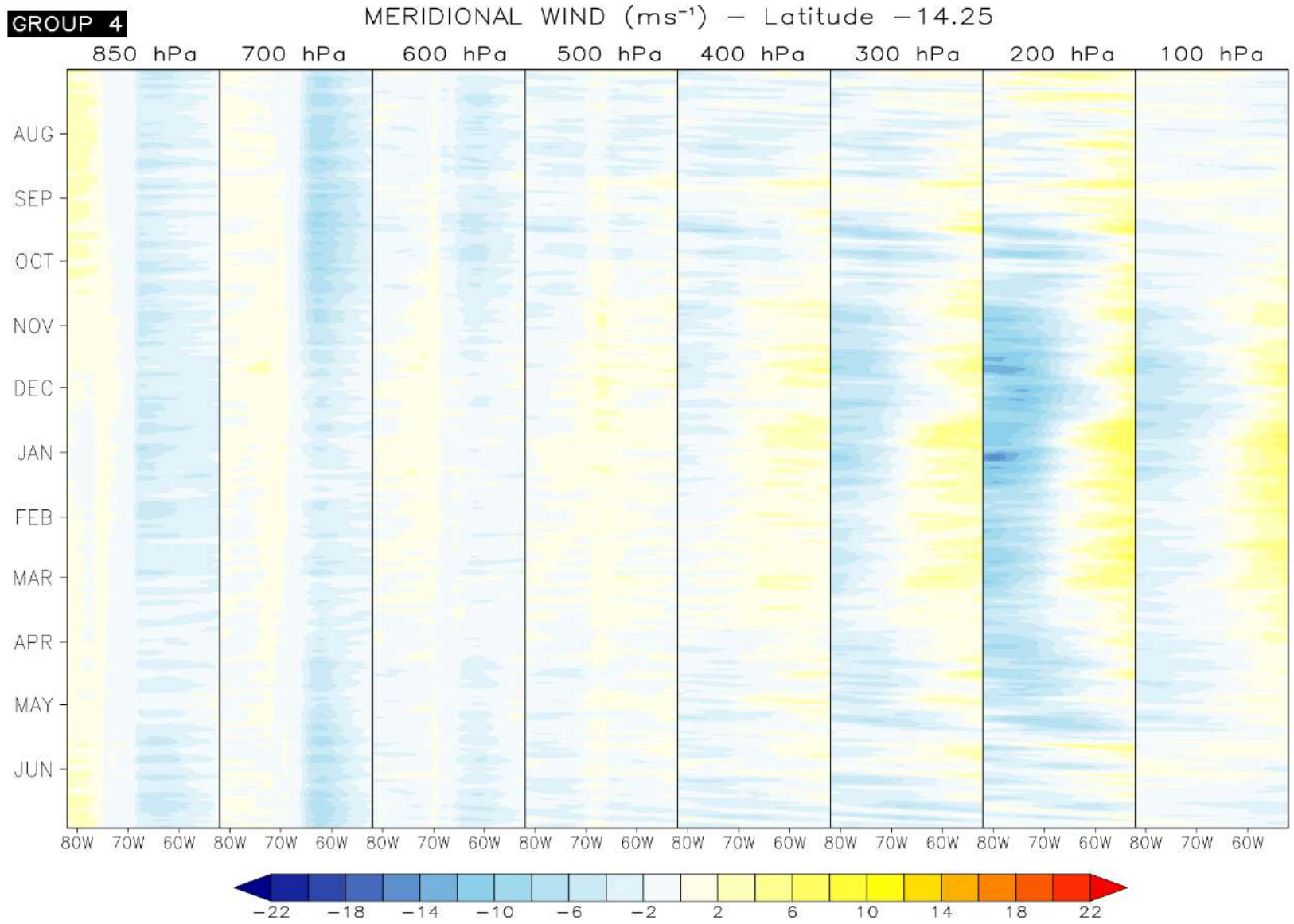


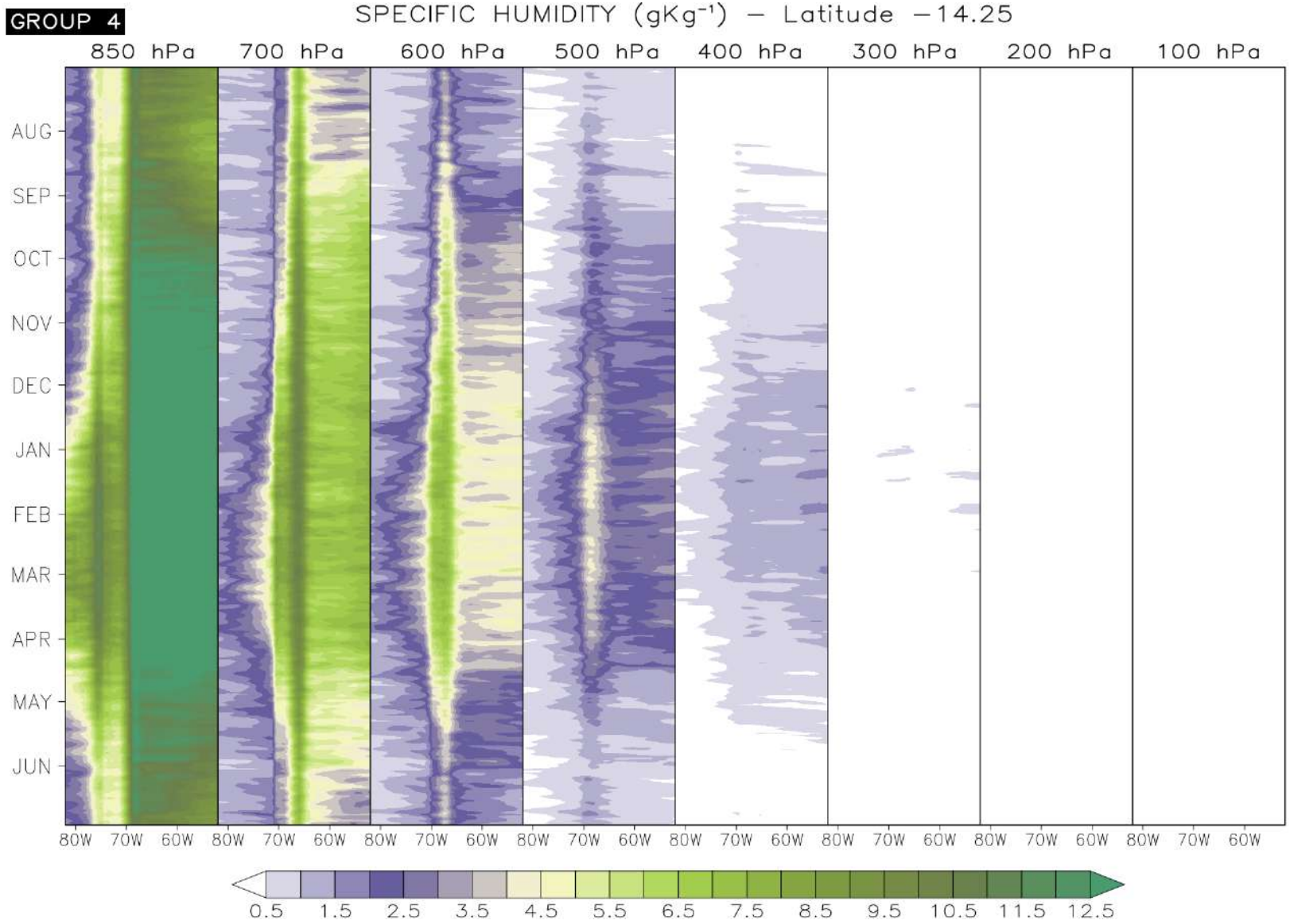
Geopotential height (*gpdm*) and wind (ms^{-1}) – 200 hPa



Vertical variation of atmospheric variables




GROUP 4
MERIDIONAL WIND (ms⁻¹) – Latitude –14.25
850 hPa
700 hPa
600 hPa
500 hPa
400 hPa
300 hPa
200 hPa
100 hPa
AUG
SEP
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
80W 70W 60W
−22 −18 −14 −10 −6 −2 2 6 10 14 18 22

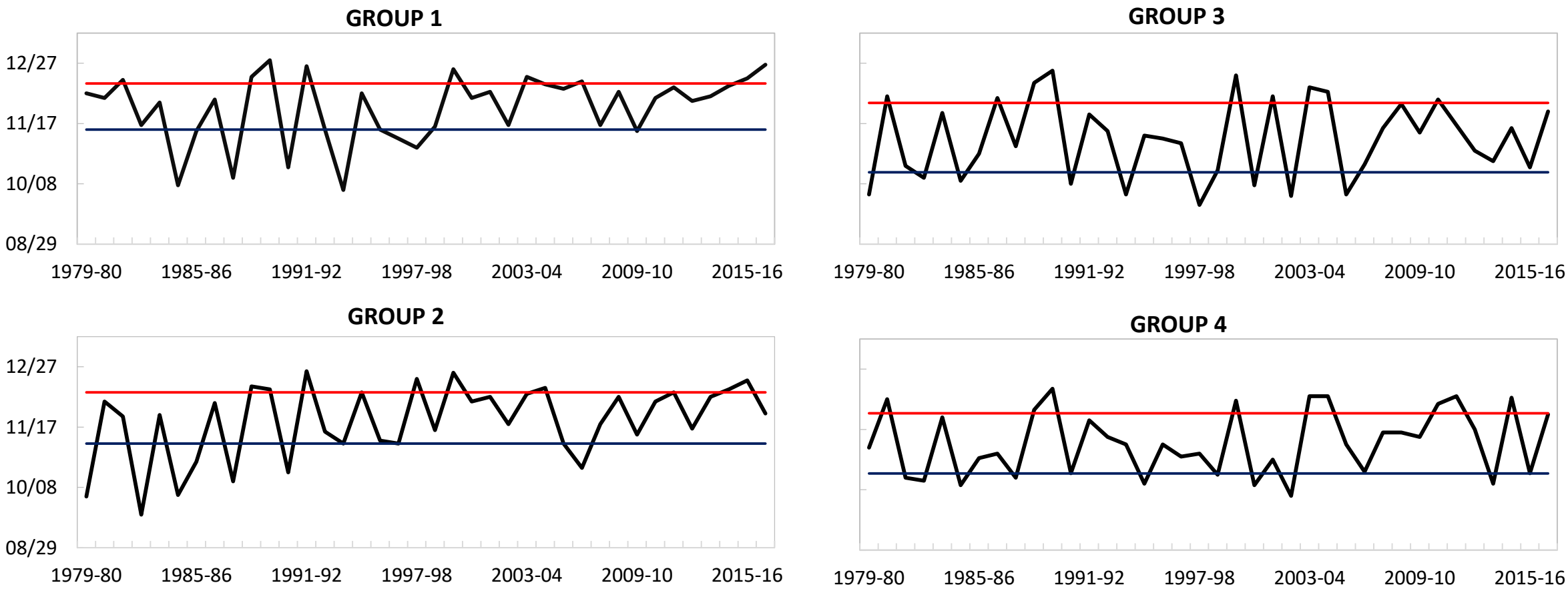

GROUP 4
SPECIFIC HUMIDITY (gKg⁻¹) – Latitude –14.25
850 hPa
700 hPa
600 hPa
500 hPa
400 hPa
300 hPa
200 hPa
100 hPa
AUG
SEP
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
80W 70W 60W
0.5 1.5 2.5 3.5 4.5 5.5 6.5 7.5 8.5 9.5 10.5 11.5 12.5

3. Comparison between early and late cases of wet season onset

Early and late cases' thresholds

- 1 and 3 Quantile (Percentile 25th and 75$^{th)}$
- Character of the cases
- ERA-Interim Reanalysis

Interannual variability



Character of the early and late wet season onset cases

EARLY

Group	Onset	End	Duration (days)	Annual precipitation (mm)	Wet season precipitation (mm)	Percentage of wet season precipitation (%)
1	28/10	04/04	160	548.5 (45.6)	450.1 (62.9)	82.1
2	18/10	10/04	176	782.4 (141.2)	684.6 (93.5)	87.5
3	06/10	06/04	184	731.7 (28.9)	651.0 (66.9)	89.0
4	13/10	08/04	179	719.5 (55.9)	633.3 (77.5)	88.0

LATE

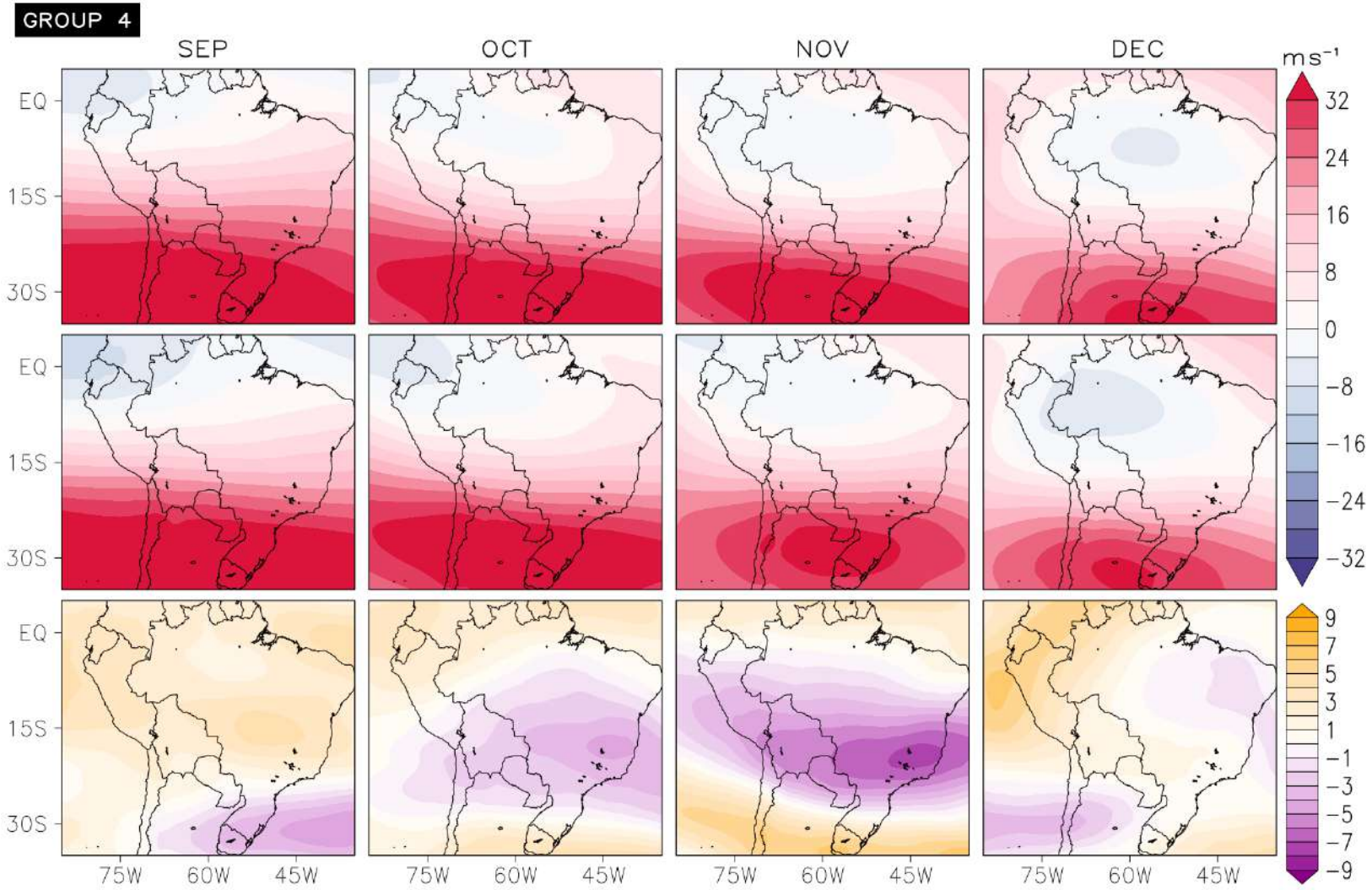
Group	Onset	End	Duration (days)	Annual precipitation (mm)	Wet season precipitation (mm)	Percentage of wet season precipitation (%)
1	20/12	27/03	93	418.8 (-84.1)	313.2 (-74.0)	74.8
2	15/12	28/03	105	591.0 (-97.9)	411.5 (-131.9)	69.6
3	10/12	02/04	116	638.7 (-64.1)	463.4 (-120.6)	72.6
4	06/12	02/04	119	626.6 (-37.1)	451.7 (-104.1)	72.1

Zonal wind: 200 hPa

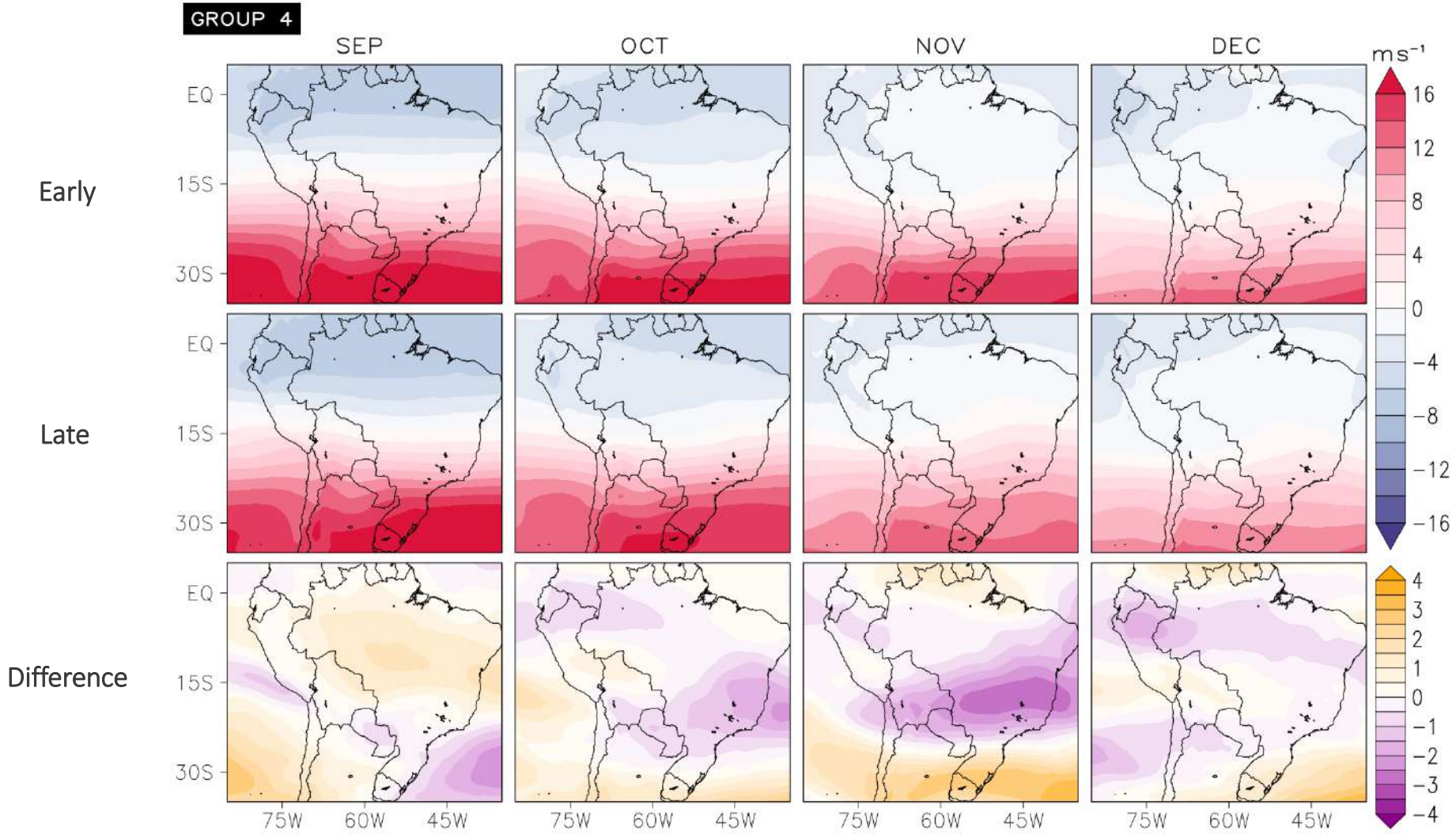
Early

Late

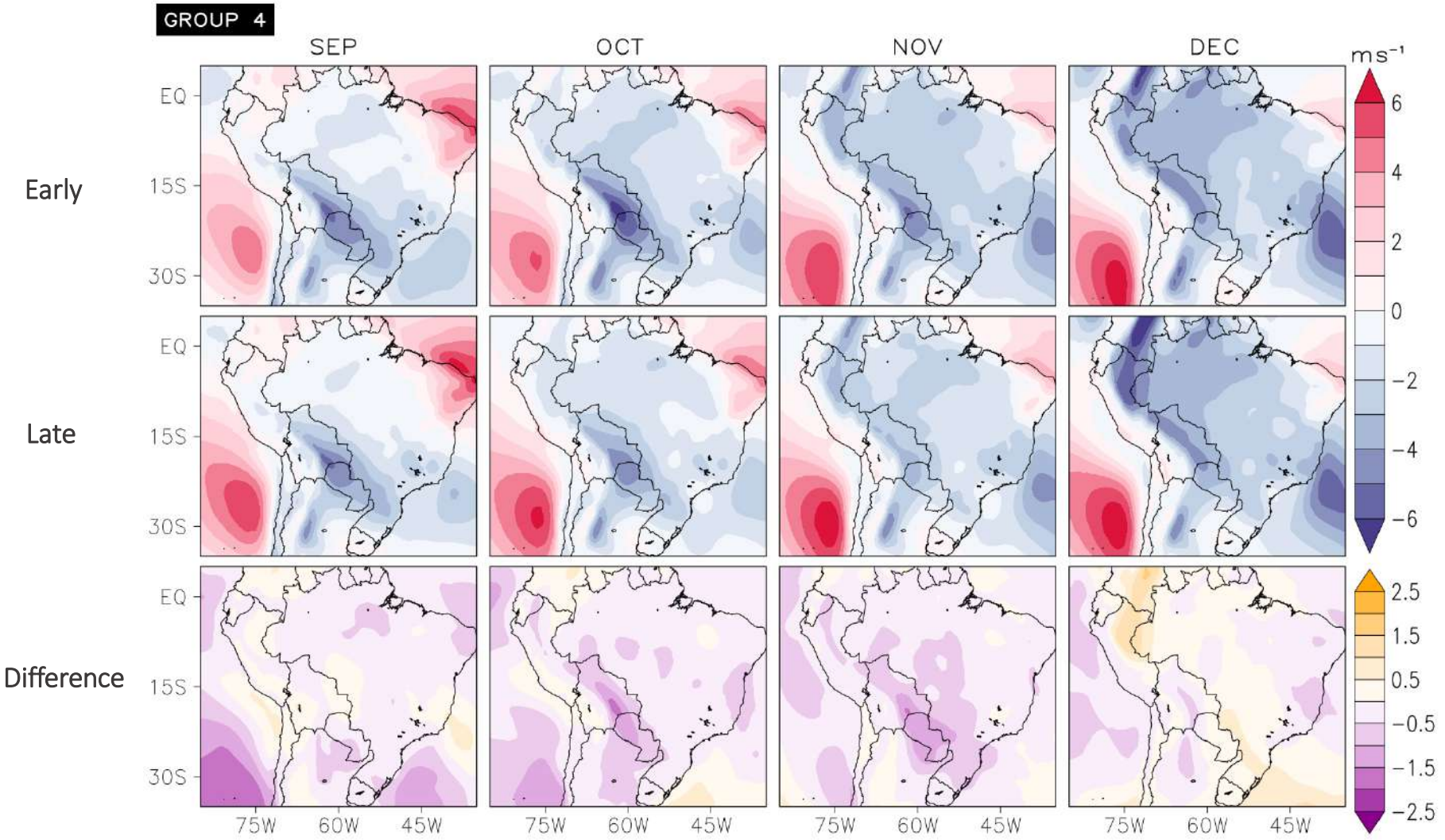
Difference



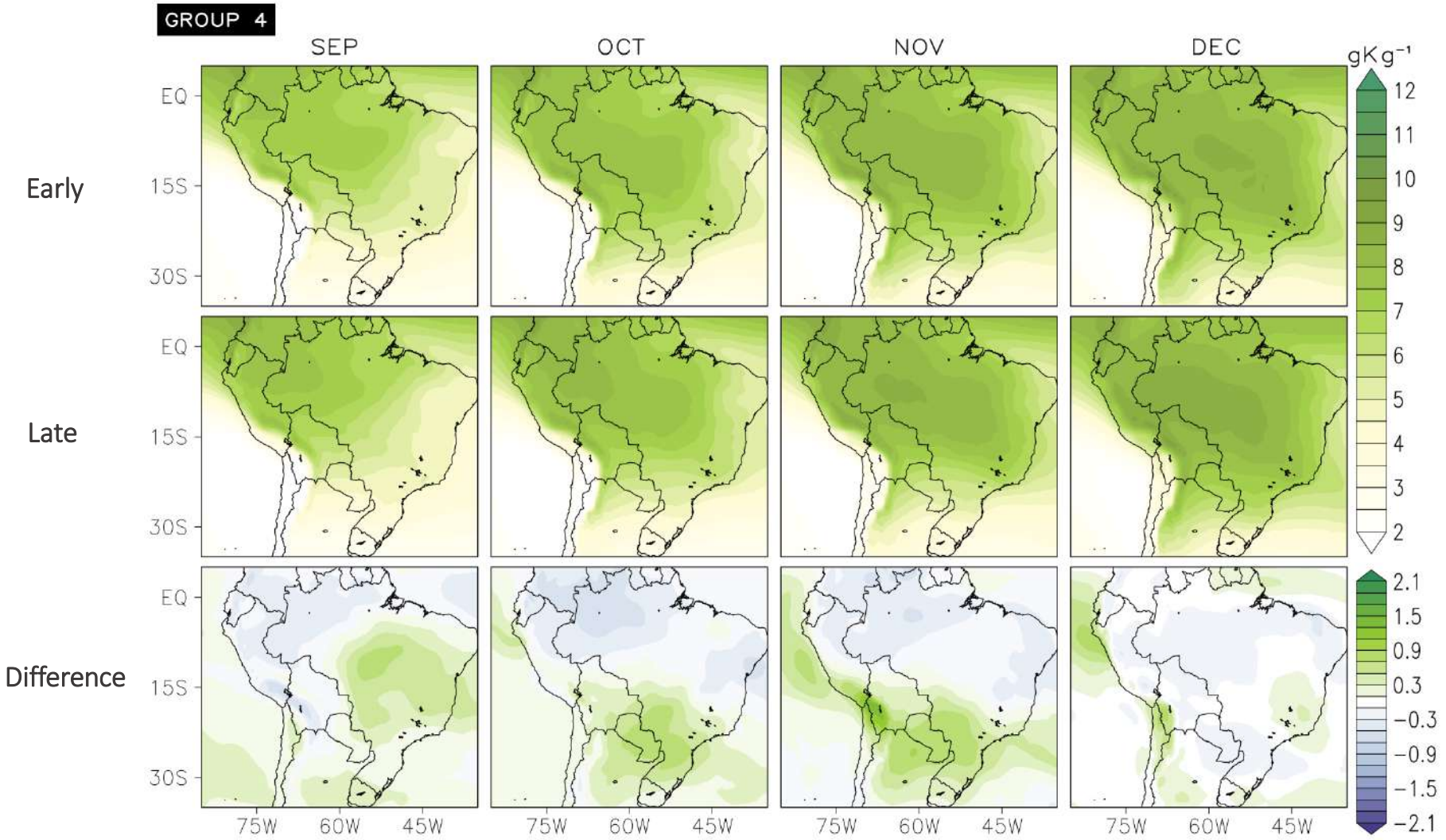
Zonal wind: 500 hPa



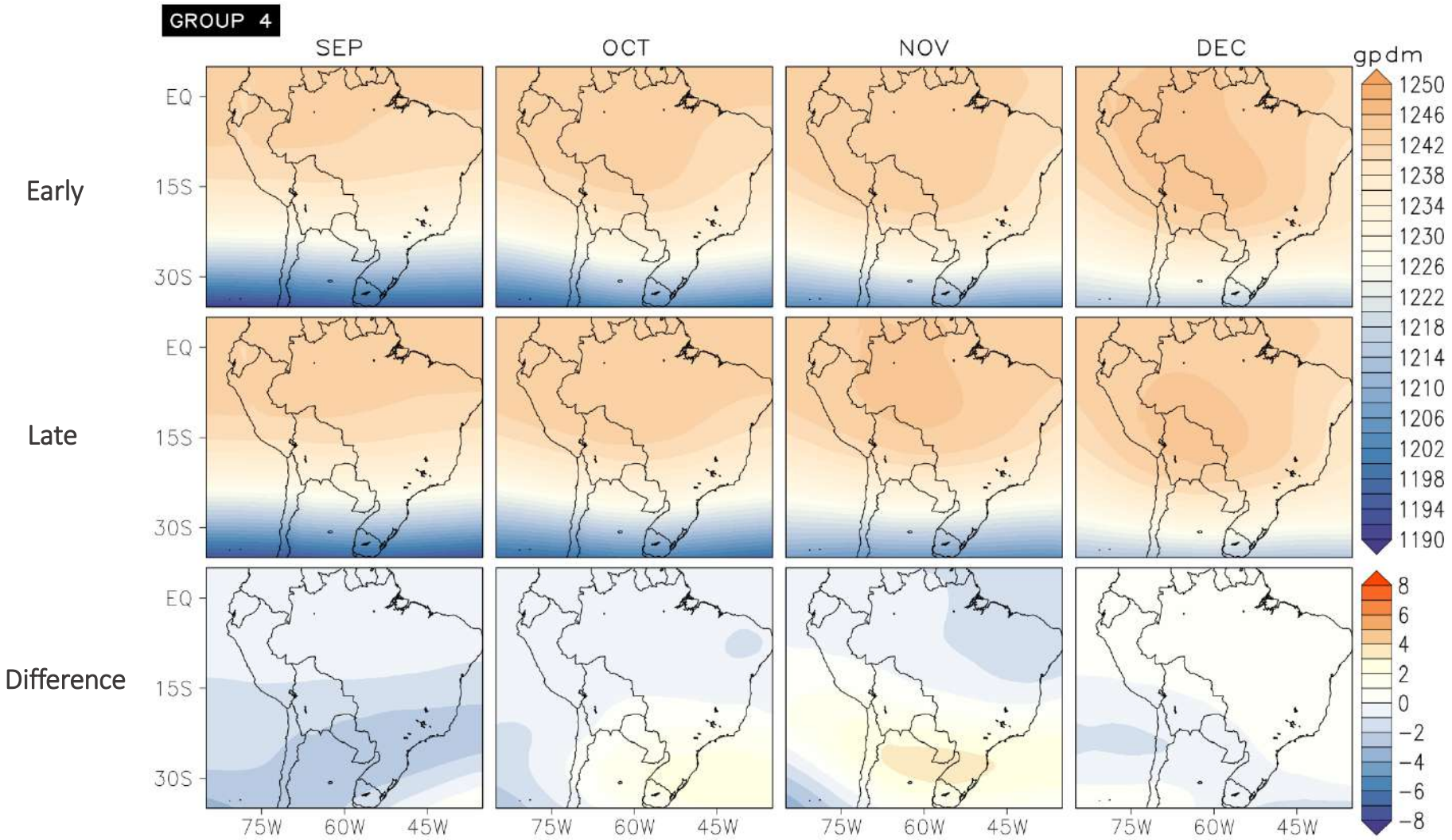
Meridional wind: 850 hPa



Specific humidity: 925/500 hPa layer



Geopotential height: 200 hPa



4. Trend analysis

Statistical tests:

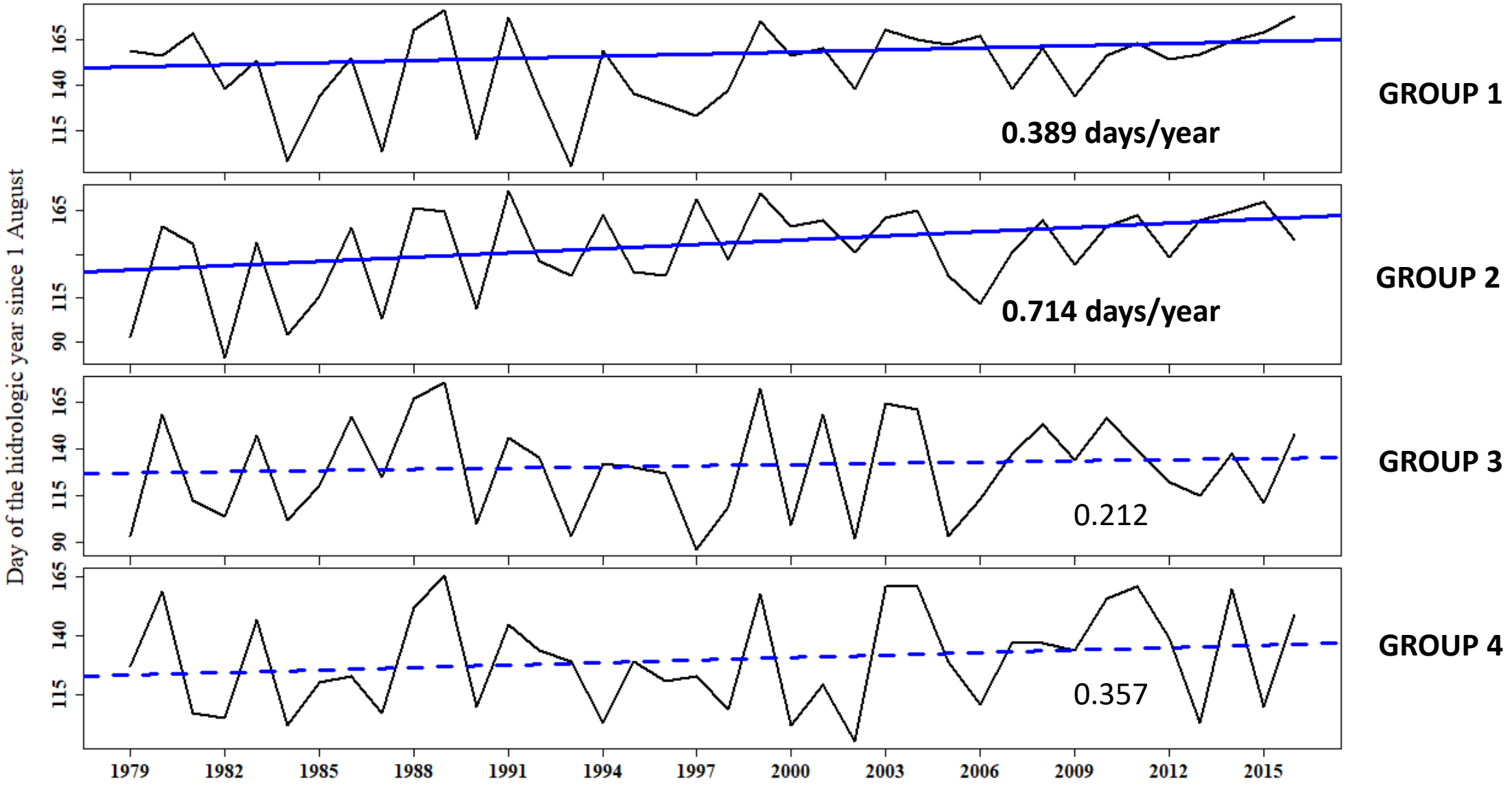
- Mann-Kendall
- Sen’s Slope (Kendall Theil Robust Line)
- Pettitt’s

Trends analysis

Trend Analysis, showing results from the Mann Kendall, two-sided (*) and one-sided-upward (**), Sen's Slope and Pettitt's test according to each subregion.

Group	Mann Kendall					Sen's slope			Pettitt's test		
	tau	S	VarS	p-value *	p-value **	slope	95% Confidence interval	p-value	Change point	Kt	p-value
1	0.206	144	6314.667	**0.0719**	**0.0360**	**0.389**	-0.037 - 1.333	**0.0719**	**1998-99**	168	**0.0989**
2	0.241	168	6314.667	**0.0356**	**0.0178**	**0.714**	0.030 - 1.538	**0.0356**	1987-88	156	0.1496
3	0.043	30	6321.333	0.7153	0.3576	0.212	-0.714 - 1.000	0.7153	2002-03	68	0.2001
4	0.138	96	6312.667	0.2318	0.1159	0.357	-0.278 - 1.133	0.2318	2002-03	147	0.2001

Kendall-Theil Robust Line



Conclusions

- Spatiotemporal variation in the wet season timing in the study area.
- Gradual transition to the summer atmospheric features such as the northwesterly low, El Chaco low, southeasterly winds in mid troposphere, and the Bolivian high.
- Well distinguish seasonality of the zonal and meridional wind, and moisture content in the atmosphere.
- Early an late wet season onset are commonly associate with positive and negative precipitation anomalies, respectively.
- Change in position and strength in the lower, middle, and upper tropospheric system are related with cases of early and late wet season onset.
- Significant trends were found in the area southwest of the Titicaca Lake showing a delay in the wet season since 1979.

Future directions

- Examine in deep trends in the end and duration of the wet season
- Examine trends in the atmosphere to explain the delay in the wet season onset in groups 1 and 2.
- Analyze in deep the interannual variability.
- Assess the social conflicts that a delay of the wet season onset may cause in Andean communities


THANKS
QUESTIONS?