Weather within climate : weather types

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Atmospheric circulation and weather types

- Atmosphere is **chaotic** ; in consequence, two instantaneous atmospheric states are never exactly identical (i.e. true analogs do not exist)
- **Bi- (or multi-) modality of atmospheric states is not yet fully demonstrated**, even for highly truncated representation of the atmosphere (as the hypothesized bimodality between « zonal » and « blocked » atmospheric circulation in the northern extratropics in winter)
- In that context, the classification into « *weather types* » (WTs) is an attempt to **aggregate instantaneous (or daily mean) atmospheric states into « clusters »** (i.e. a group including similar atmospheric patterns even if they are not strictly identical) and WTs are usually defined as composite means of observations belonging to it (= centroids)
- WTs are usually computed using spatially-consistent variables (as sea level pressure or geopotential height -Z- at 500 or 700 hPa in extratropics) to filter out the small-scale variability
- WTs are usually computed at **regional scale** (i.e. several 10s of degrees in longitude/latitude) but also at zonal scale (at least on extratropics), mostly on a given season
- **Mean annual cycle is usually removed**, assuming that it is constant at interannual time scale. This *a priori* filtering could be detrimental due to potential aliasing between time scales

Weather types in extratropical zone

- In the extratropics, WTs have been usually defined as an **intermediate scale between synoptic scale (i.e. travelling low pressure systems) and annual cycle (i.e. speed of westerlies and location/intensity of associated barometric center of actions)**. In particular WTs help to define the trajectory and location of the storm tracks associated with recurrent **slow/stationary ridge/troughs systems**
- « *Grosswetterlagen* » as those defined for British Isles (Lamb, 1972) are obtained through a **supervised classification** of atmospheric patterns associated with the location of anticyclone and low pressure systems and associated flow over a country or a small region ; these classifications lead usually to a lot (more than 10) of different WTs allowing a precise regionalization of associated local-scale temperature and rainfall anomalies
- Then, WTs have been defined using **unsupervised techniques** (including hierarchical and dynamical clustering, gaussian mixture model, self-organizing maps etc.) mostly at zonal and regional scales, mostly in winter (cf. studies of Legras, Vautard, Mo, Kimoto, Ghil, Chen, Wallace et al. etc.). **These classifications lead usually to few atmospheric patterns** (except for SOM), for example 4-5 WTs in and around the Northern Atlantic in winter (« Zonal », « Blocking », « Atlantic Ridge » etc.)

Weather types in tropical zone

- Definition of WT in the tropical zone is more recent than in extratropics (i.e. Pohl et al., 2005 ; Moron et al., 2008), even if typical equatorial circulation patterns, i.e. « *drift* » (= trans-equatorial flow between an anticyclone and a depression on each side of the equator), « *duct* » (= two symmetric anticyclones on each side of an equatorial low pressure) or « *bridge* » (= two symmetic depressions on each side of an equatorial high pressure) + secondary patterns as « diamond », « shifted duct » etc. (Johnson and Mörth, 1960) are, in essence, similar to a supervised weather type classification
- SLP (and especially Z) are less relevant in the tropics than in extratropics : tropospheric winds (and/or divergence) and/or OLR/vertical velocity (as a proxy of deep convection) could be used to analyse the tropical atmospheric motions with a focus on location/intensity of divergence/convergence areas associated with thermal direct circulations of various sizes and where ascendance is tightly related to warm SST over ocean
- As in extratropics, WTs filter out the fastest and smallest scales (as meso-scale clusters, tropical depressions or cyclones), at least their transient and not reproducible properties
- WTs emphasize the recurrent features of atmospheric circulation at intermediate and long time scales
- WTs could be viewed as a different, but a complementary, approach of the atmospheric circulation with a space-time analysis of a specific bandwidth (« particle » vs « phase » approaches in Ghil and Robertson, 2002)

Outline

1- Examination of a simple example to illustrate the links between *statistical* clusters and *dynamical* attractors

2- Analysis of the weather types over the Caribbean basin (98.75°W-56.25°W, 8.75°N-31.25°N) using daily 925 hPa winds and OLR all year around from 1979 to 2013

3- Mean properties of WTs ; mean annual cycle and centroids & relationships with local-scale rainfall (from daily GPCP 1° x 1° grid from 1996 to 2013)

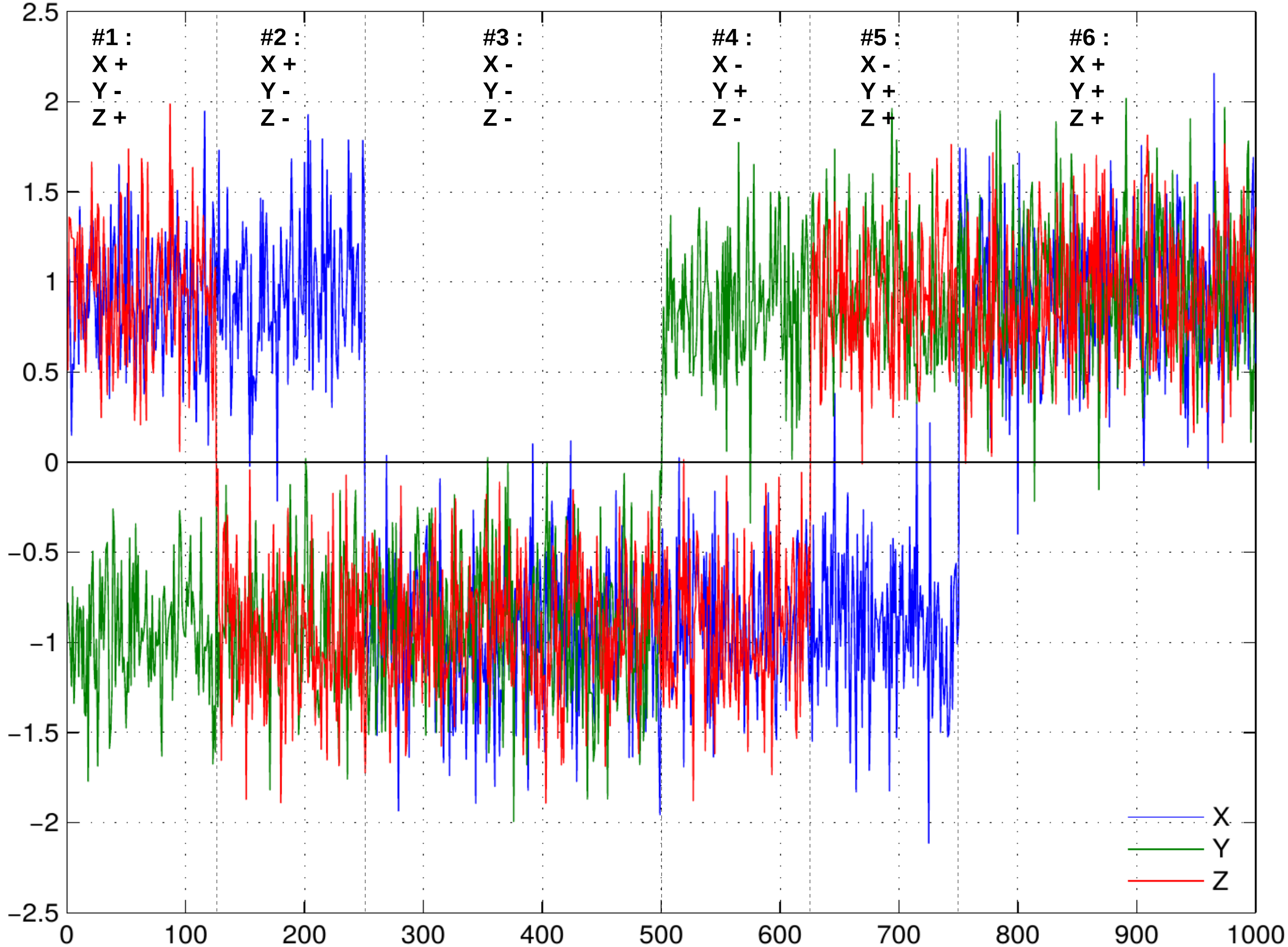
4- What can we infer from WT occurrence and sequentiality : two examples about synoptic motions and regional-scale onset and withdrawal of the « summertime » WTs

5- Potential predictability of WT occurrence from SST (including ENSO)

6- Concluding remarks

7- References

1- A simple 3-variable system



Consider a 3-dimension system, where each variable (X,Y,Z) equals either -1 or +1 (+ Gaussian independent white noise) during 1000 time steps.

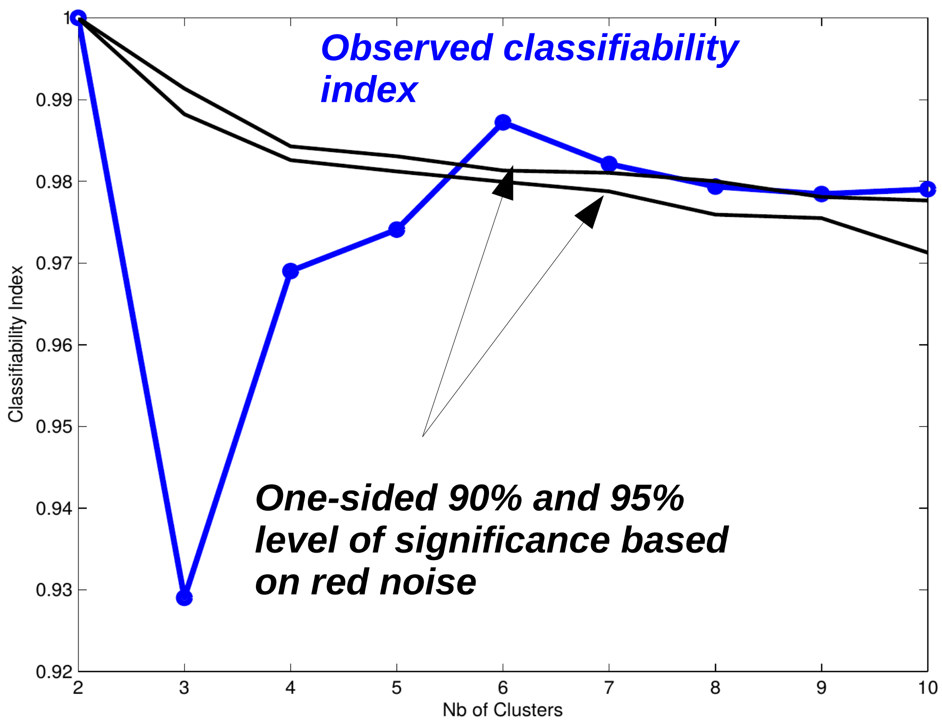
By construction, there are 8 possible 3-dimension attractors (defined by either positive or negative values for each variable) in the whole phase space defined by the 3 dimensions (- - + & + + - do not occur in our sample)

1- K-means dynamical clustering

Dynamical clustering techniques classify observations (in N dimensions) so that the intra-cluster variance is minimized. K-means (Diday and Simon, 1976) is an iterative method ;

- M (= nb of clusters) random seeds are chosen
- all observations are clustered with the nearest seed
- the centroids of the M clusters are computed and are considered as the new seeds for the next step
- this is repeated till a convergence criterion about the variations of intra-cluster distance to the centroid is reached

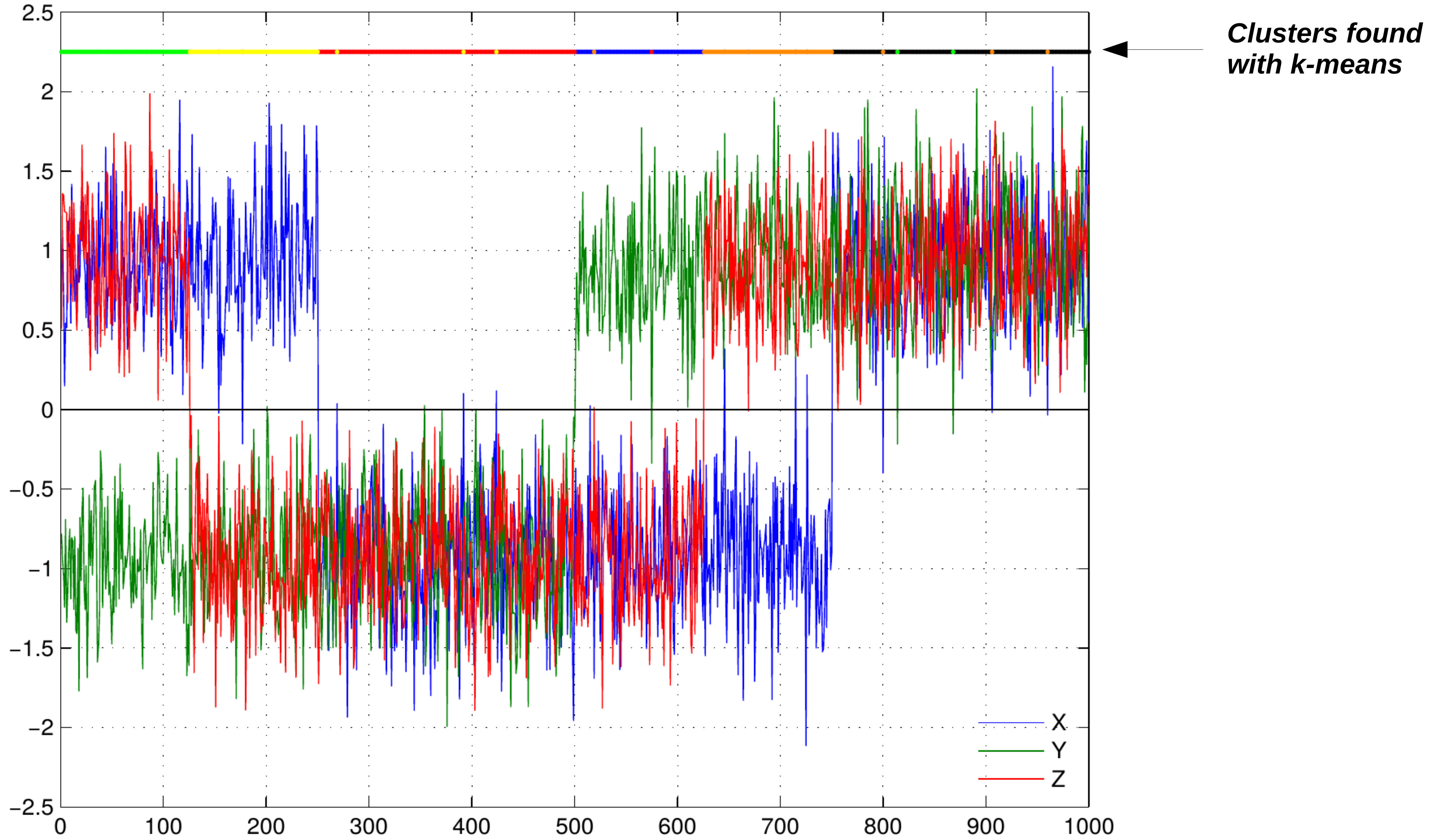
Several criteria could be used to define the « optimal » number of clusters



Here, the criteria is a classifiability index, modified from Michelangeli et al. (1995), which measures the sensitivity of the final clustering to the initial choice of random seeds

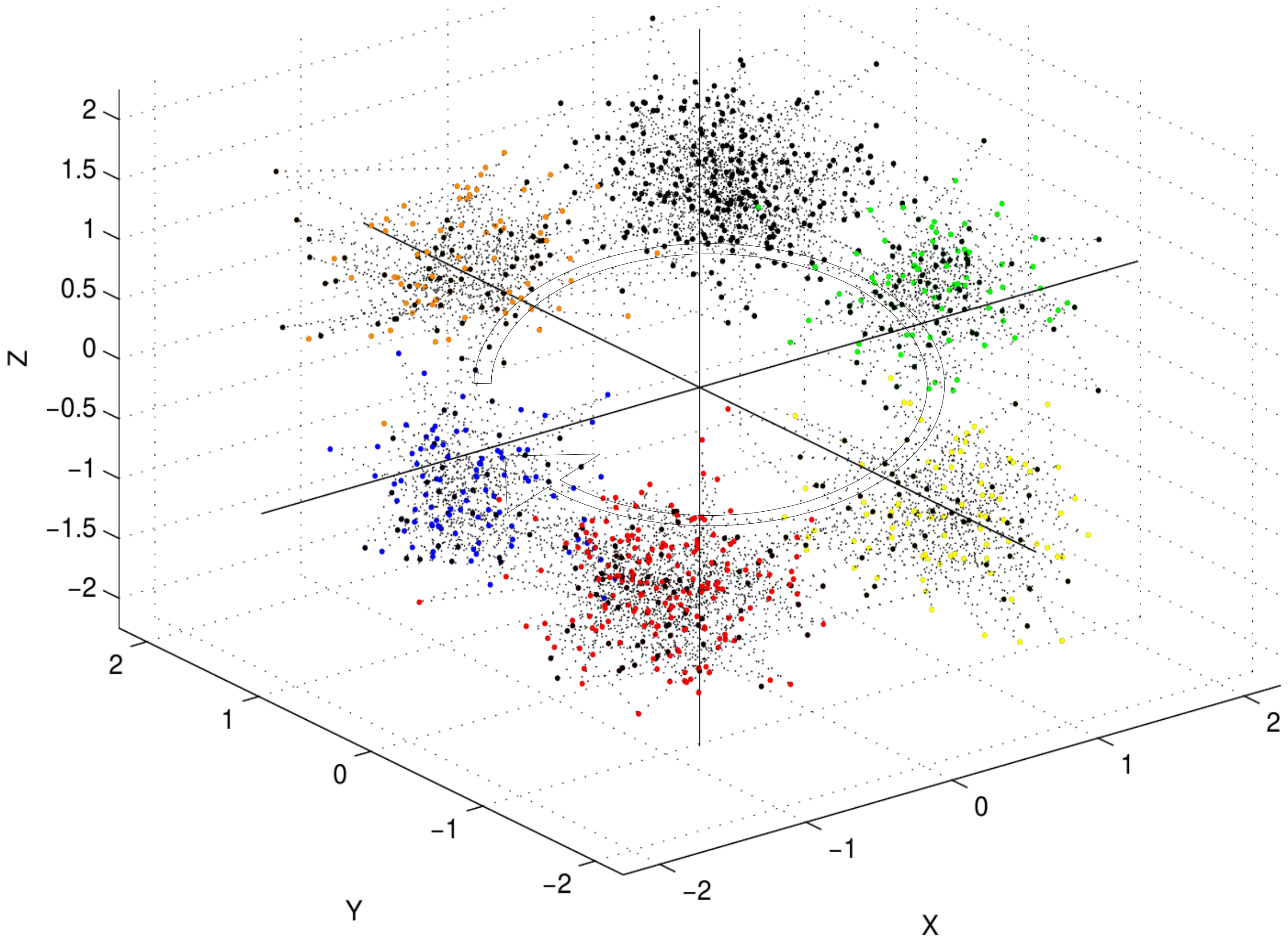
The « optimal » solution is reached for 2 clusters (mostly because the joint PDF is bimodal, i.e. around +1 and -1) and the **number of 6 clusters, expected by construction**

1- Detection of the 6 clusters using k-means



On top is indicated the 6-cluster solution in colored dots. The Gaussian noise could interrupt the sequences of clusters but the 6 clusters are well defined with the k-means

1- *Statistical* clusters vs *dynamical* attractors



Dotted lines connect successive temporal observations while colors identify the membership to the 6 clusters shown on previous slide

The 6 ***statistical clusters*** ~ empirical estimates of the ***basin of the dynamical attractors***, i.e. sub-spaces in the phase space where the 3-variable system has an high probability to evolve. If noise = 0, the 6 attractors are **fixed points** in the 3-dimension space. When noise > 0, the centroids of the clusters are empirical estimates of these unknown attractors

1- Finding dynamical attractors in the climate system ?

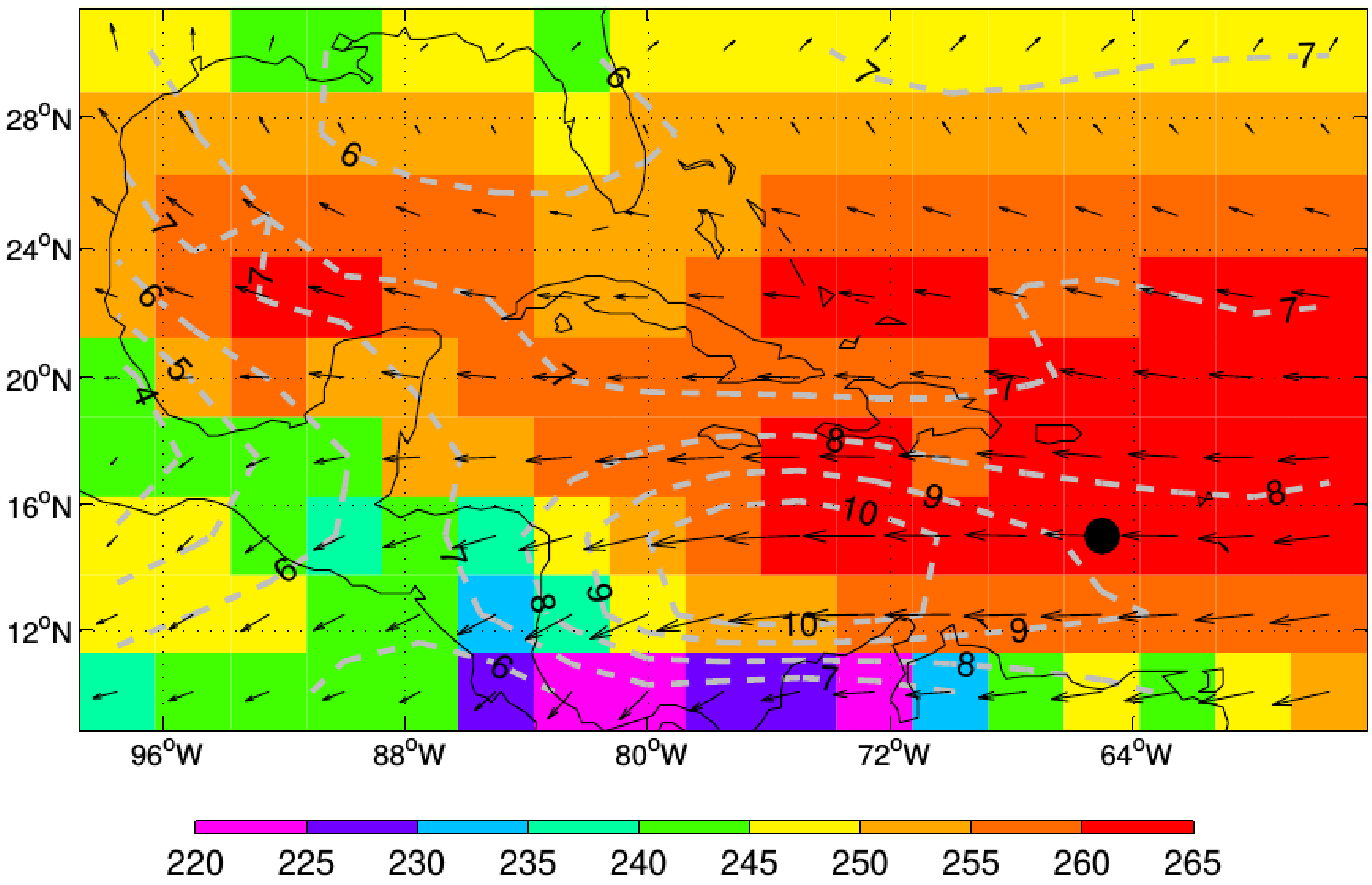
Previous studies, as Lorenz (1963), found attractor in very simple deterministic systems (3 variables in case of Lorenz, 1963)

Is it possible to find attractors of the climate system ? The answer is not trivial for at least 3 reasons ;
(1) the climate system includes **a huge number of different dimensions** (which is a practical issue since we have only finite – and short – records, contaminated by various noises to define the attractors)
(2) the climate system is forced by continuous various forcings which lead to a **continuum of time scales** (still unclear that climate system or one of its sub-system as atmosphere exhibit bi- or multimodality)
(3) the climate system is chaotic (attractors are not fixed points in that case but are « strange » attractors, that are objects with non-integer dimensions ; Lorenz system ; d ~ 2.7. In chaotic systems, it is also impossible to get exact analogs of a given instantaneous state)

Remind that the 3-variable model and 2 discrete states (M) = $M^N = 2^3 = 8$ possible attractors ; with 4 variables and 2 discrete states = $2^4 = 16$ possible attractors ; with 4 variables and 3 discrete states = $3^4 = 81$ possible attractors, etc.

Thus **defining « true » attractors with the short records and large dimensions of the climate system or even its atmospheric sub-component seems not feasible ...**

2- The Caribbean basin : mean climatological features



Mean annual wind at 925 hPa (vectors with speed in m/s as gray lines) and Outgoing Longwave Radiation (OLR) at the top of atmosphere in W/m². OLR come from the interpolated daily NOAA dataset and the wind comes from NCEP Reanalyses 2. All data are from Jan 1 1979 to Dec 31 2013

Almost constant trades (reaching > 10 m/s in the south of the basin = Caribbean Low Level Jet -CLLJ-) and large-scale subsidence (associated with thermal direct circulation) over most of the Carribean basin + InterTropical Convergence Zone -ITCZ- restricted to South America, Eastern Pacific + Central America monsoon circulation in boreal summer. The black dot indicates a grid-point in the trades …

2- The interaction of multiple time scales (1)

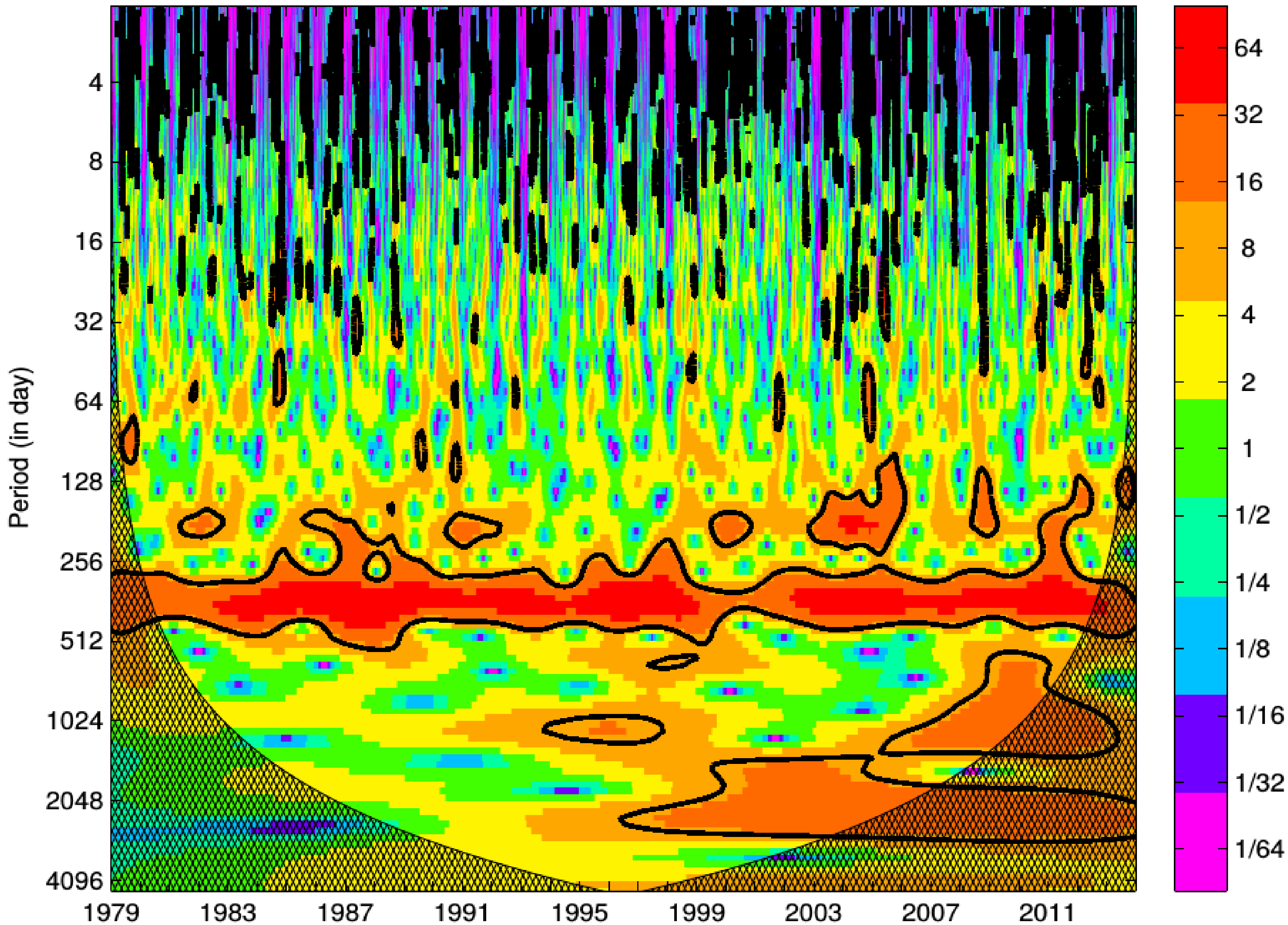
Diurnal cycle is by definition
not sampled with daily values

Meso-scale and synoptic scale from 2 to ~10 days

Intraseasonal variance from ~10 to ~ 100 days

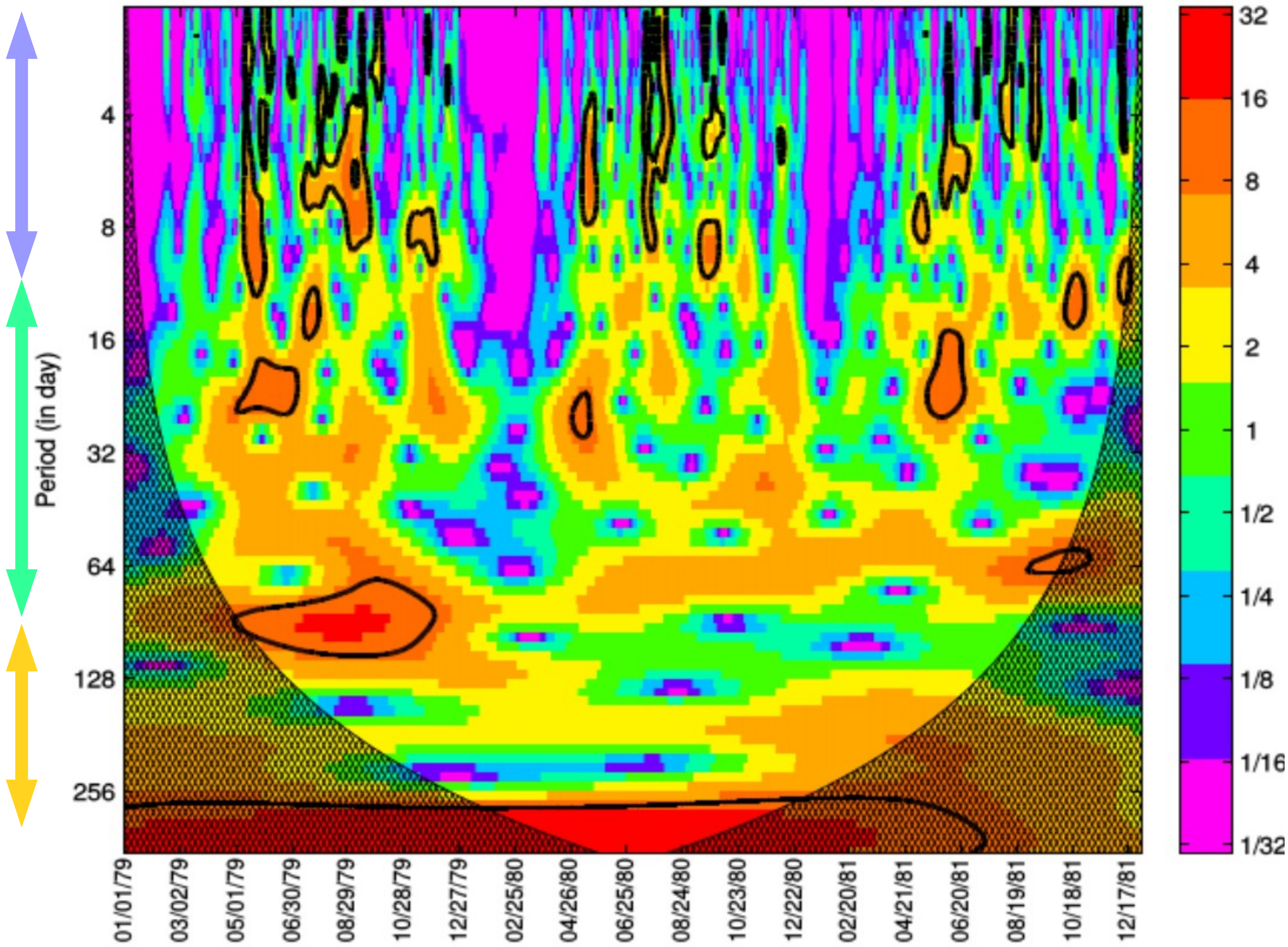
Annual cycle (+ its two first harmonics near 182 and 122 days)

Interannual variability (ENSO, Atlantic ocean, etc.)



Continuous wavelet transform of daily OLR at 65°W and 15°N from 1979, Jan 1 to 2013, Dec 31 (black contour = significant amplitude at the 95 % level)

2- The interaction of multiple time scales (2)



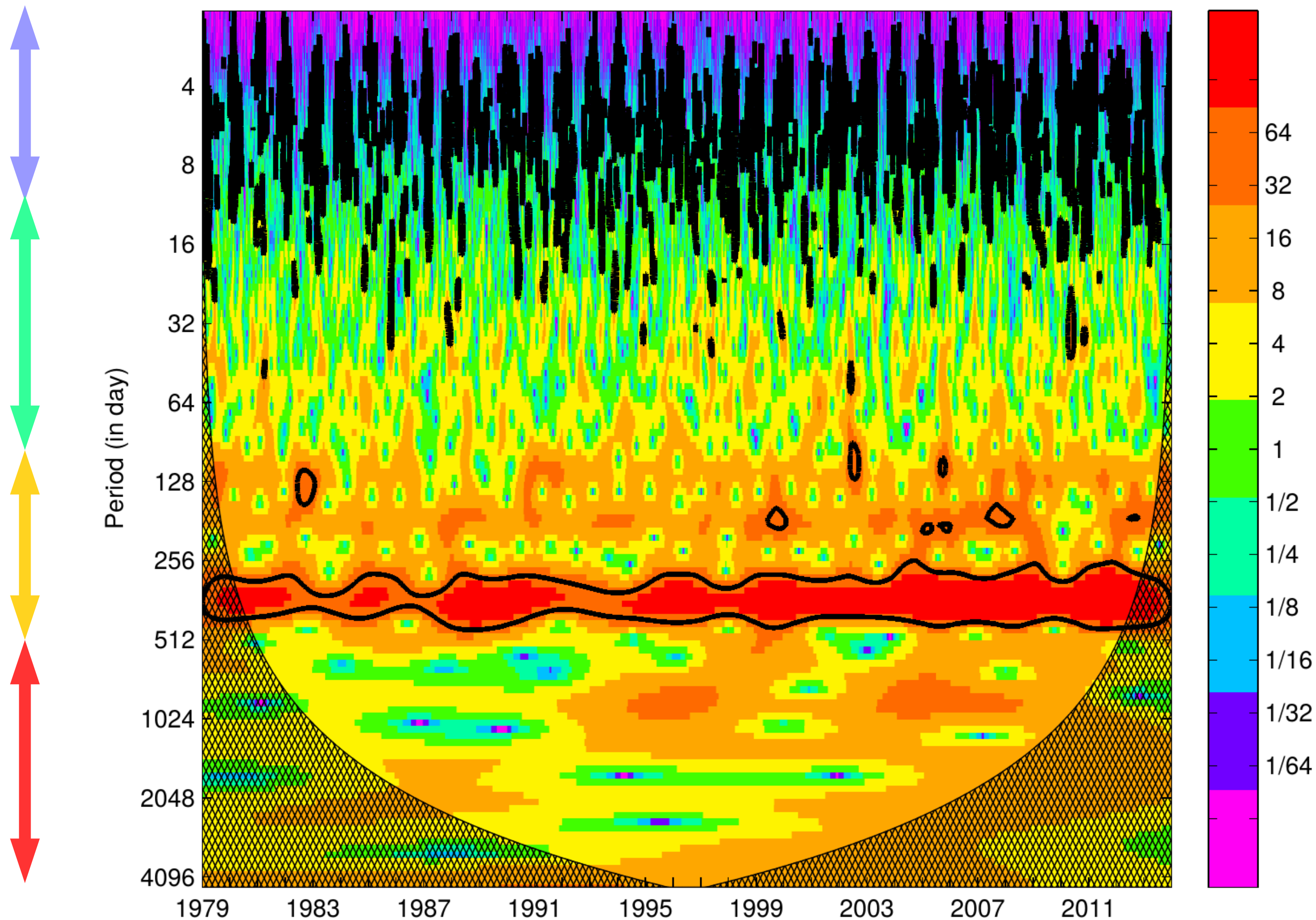
Focus on the first 3 years ; the fastest time scale < 2 weeks are strongly modulated by annual cycle : mostly active in an extended summer season roughly from May to November (Easterly waves ?) & 15-25-day variance mostly active at the start and near the end of the summer season

Continuous wavelet transform of daily OLR at 65°W and 15°N from 1979, Jan 1 to 1981, Dec 31 (black contour = significant amplitude at the 95 % level)

2- Necessary filtering of space-time variations

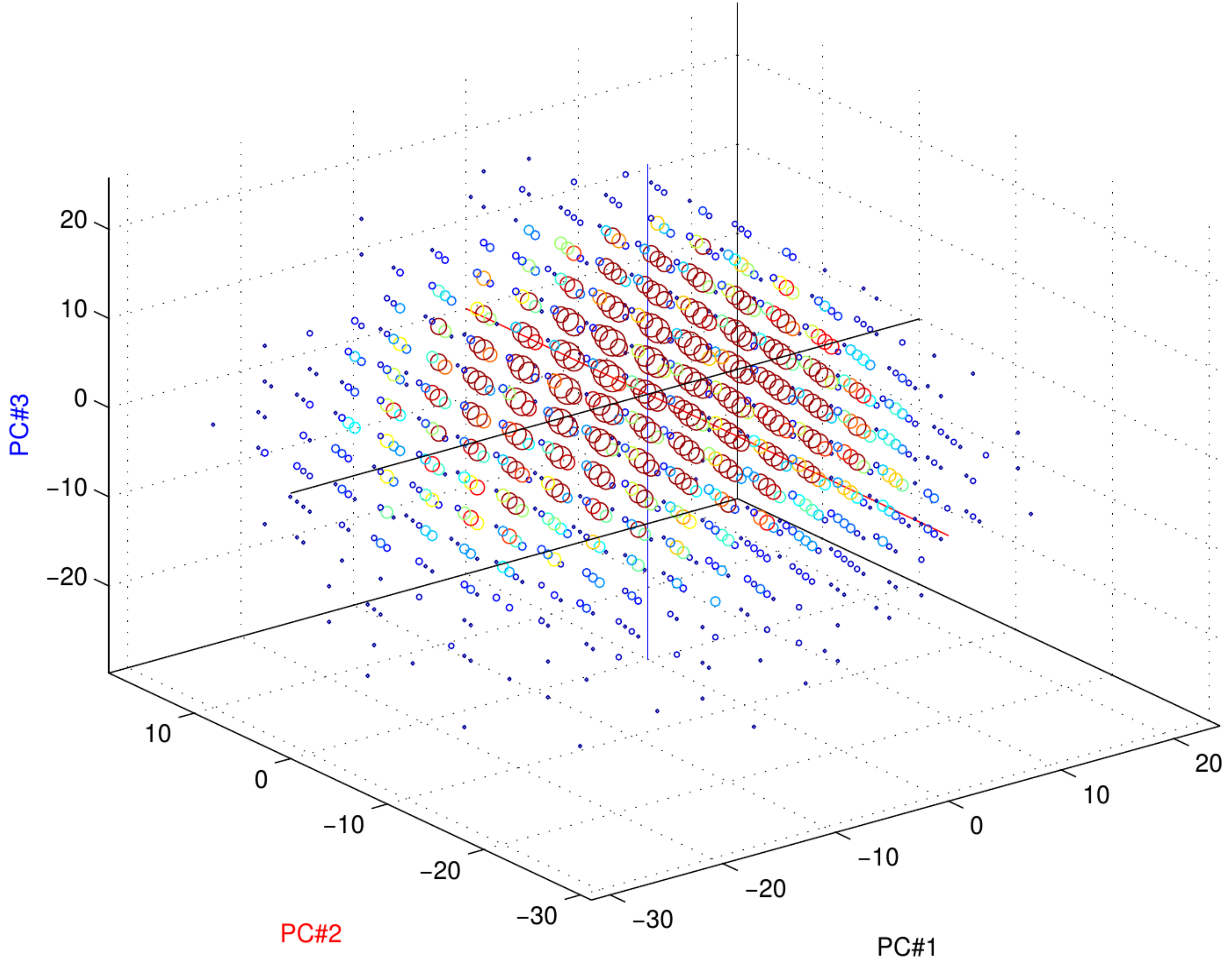
- Previous two slides consider a SINGLE grid-point and a SINGLE variable (OLR) …
- Considering regional-scale and multiple variables on a grid multiplies the degrees of freedom of the sampled atmspheric variations. This is a practical issue to define WT/attractors since the available records are short, thus leading to a large sampling uncertainty … BUT
- In the tropics, there are physical links between variables as the well-known relationship between low level convergence, vertical ascendance and the surface temperatures (especially over sea when sea surface temperatures – SST- between ~ 25°C and 29°C, i.e. warmest SST corresponds to low-level convergence and vertical deep convection partly fuelled by the latent heat release)
- These coupled processes tend to reduce physically the degrees of freedom for example through regional- to large-scale thermal direct circulation (as Hadley/Walker cells, monsoons, ENSO etc.) linking horizontal/vertical motions and surface temperature on >> 10^6 km² patterns which significantly impacts smaller and faster phenomena
- The degree of freedom could be also a priori reduced in a data-adaptative way with an EOF pre-processing to retain the largest spatial scales of atmospheric motions

2- The interaction of multiple time scales (3)



Continuous wavelet transform of the leading unfiltered principal component of joint OLR and wind zonal and meridional component at 925 hPa from 1979, Jan 1 to 1981, Dec 31 (black contour = significant amplitude at the 95 % level)

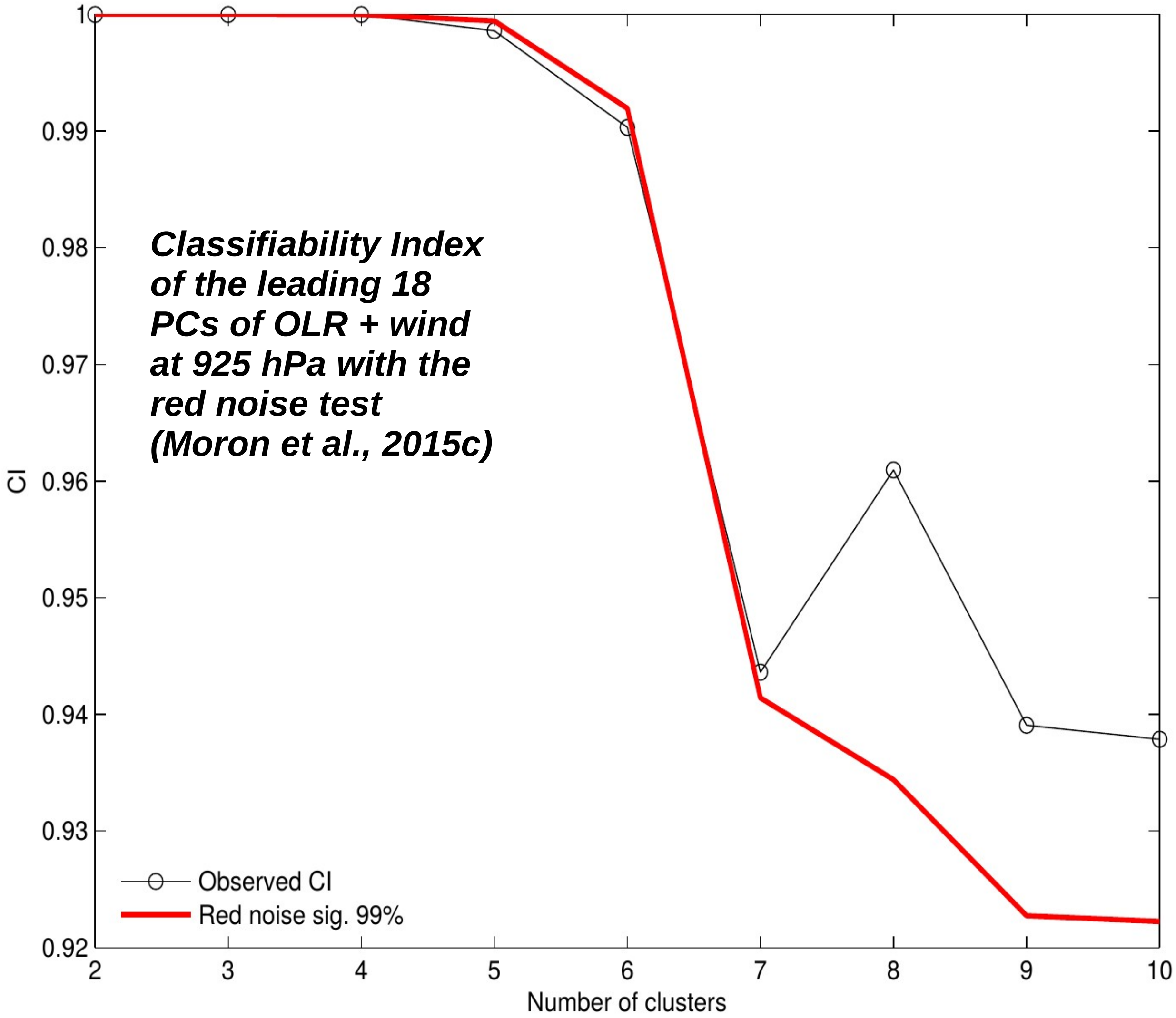
2- The detection of attractors ?



Joint PDF of the leading 3 PCs of combined OLR and wind at 925 hPa over the Caribbean basin (= frequency per box of 3 units)

There is no clear evidence of multi-modality. We need to consider **clustering just as a data-adaptative tool to find recurrent coarse-grained atmospheric patterns (i.e. Ghil and Robertson, 2002) without any a priori dynamical interpretation in terms of dynamical attractors**

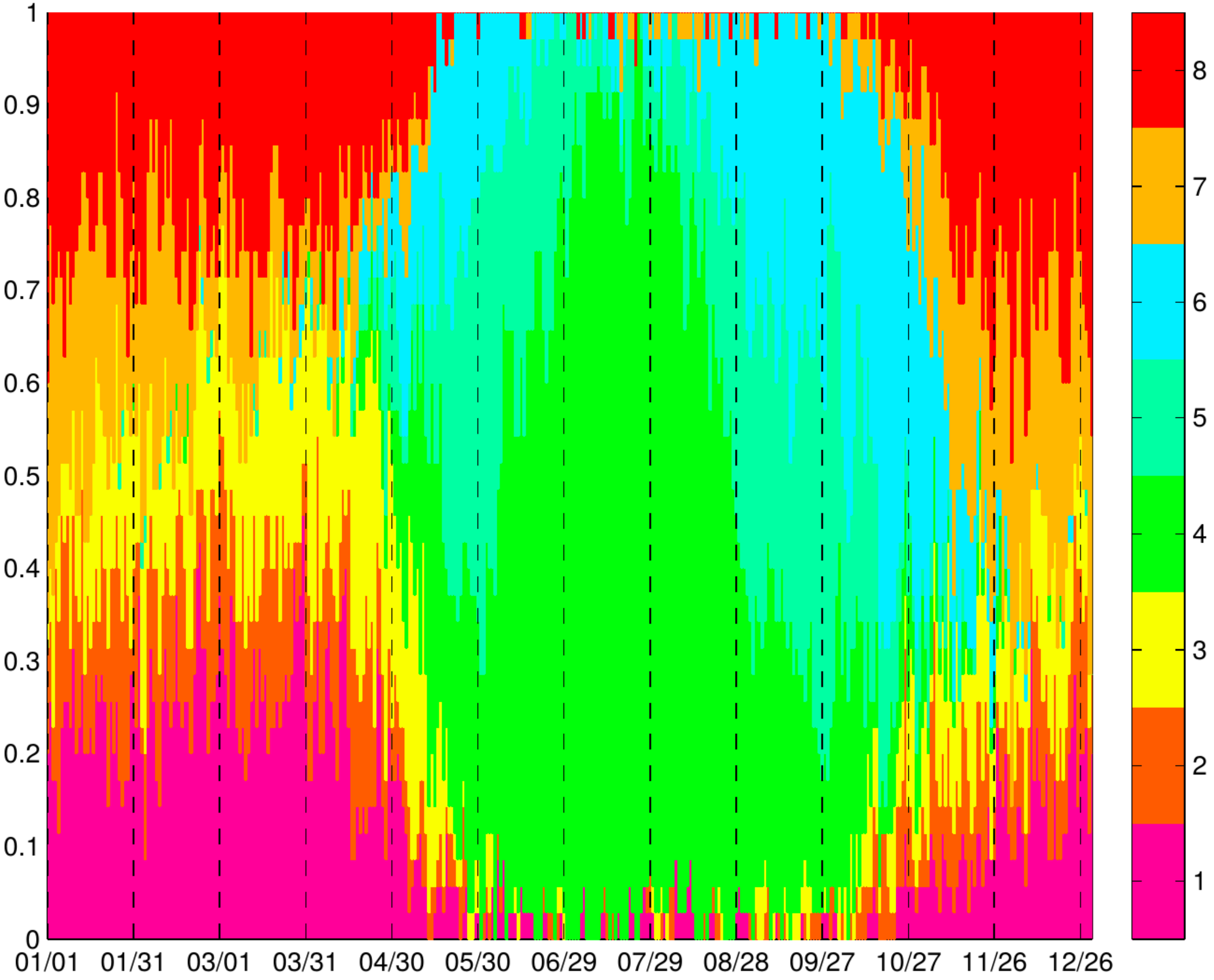
2- The number of weather types



8 clusters sound a good compromise between resolution and physical interpretation, but other authors analyze 8 (Chadee and Clarke, 2015) or 11 (Saenz and Duran-Quesada, 2015) clusters while their physical interpretation is as valid as the one displayed in this lecture …

So, it is not usefull or necessary to brainstorm too seriously on the number of clusters …

3- Mean annual cycle of WT frequency

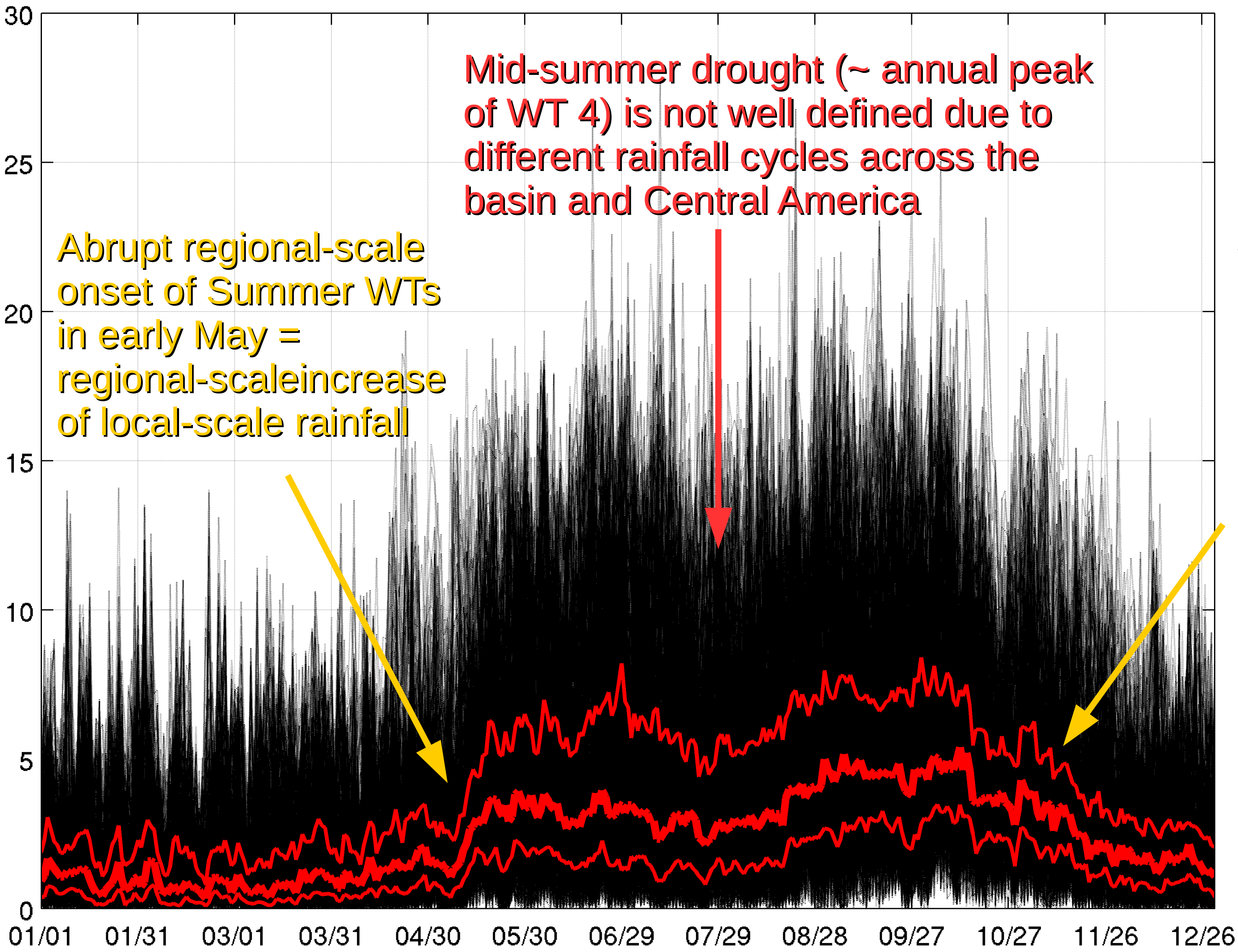


Cumulative mean daily frequency of WT occurrence from 1979 to 2013 (Moron et al., 2015c)

Main difference between « summertime » (4-6) and « wintertime » (1-3 & 7-8) WTs with an abrupt transition in early May from Summer to Winter and a more gradual one in October- November

In summer, bi-modal peaks of WT 5-6 occur around a large maximum of WT 4 in July ~ during the mid-summer drought -MSD-

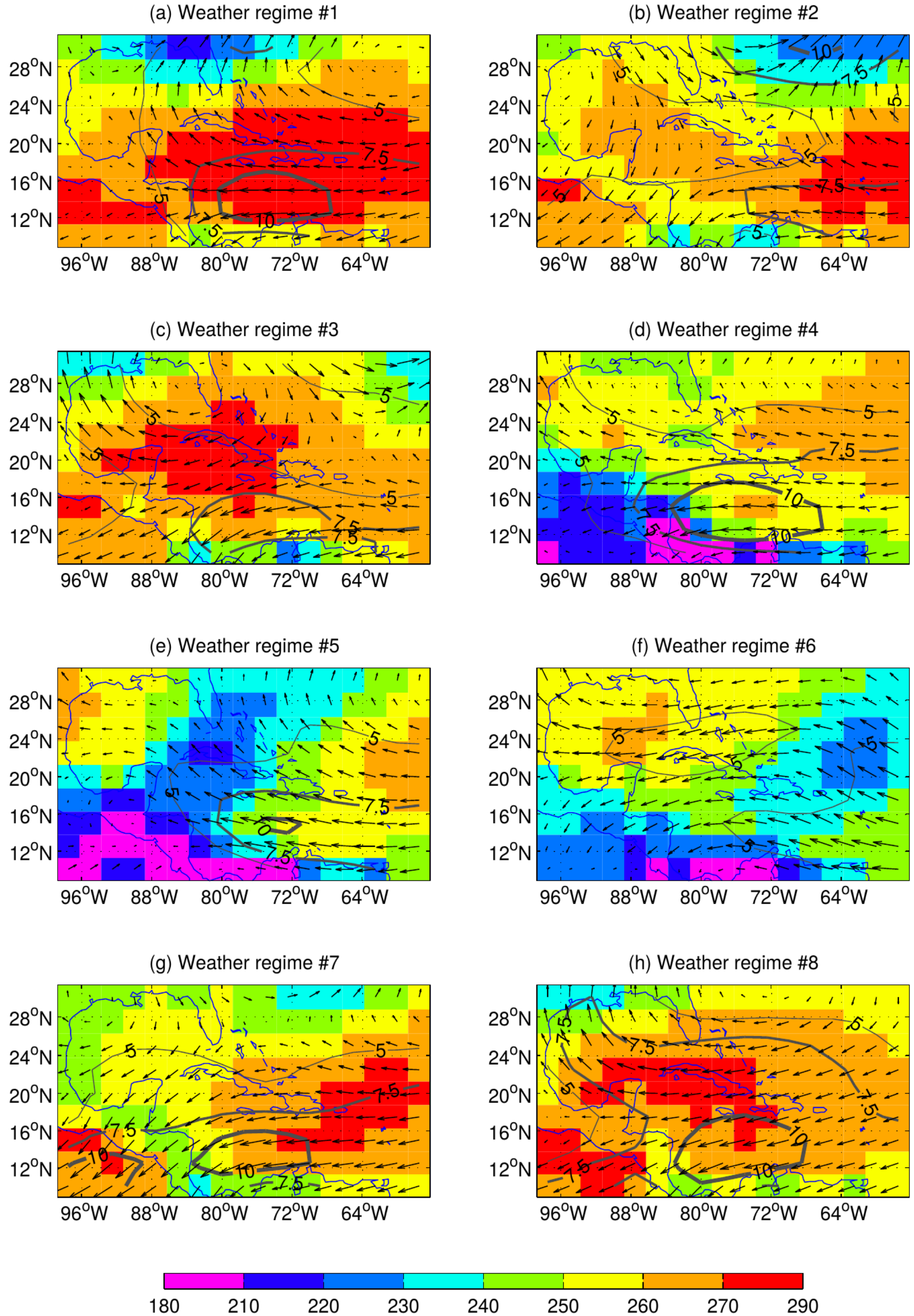
3- Mean annual cycle of rainfall



Mean annual cycle of GPCP rainfall (from oct 1996 only) with 25,50,75th percentiles across the whole area

More diffuse regional-scale decrease of local-scale of rainfall when Winter WTs increase in frequency

3- WT centroids

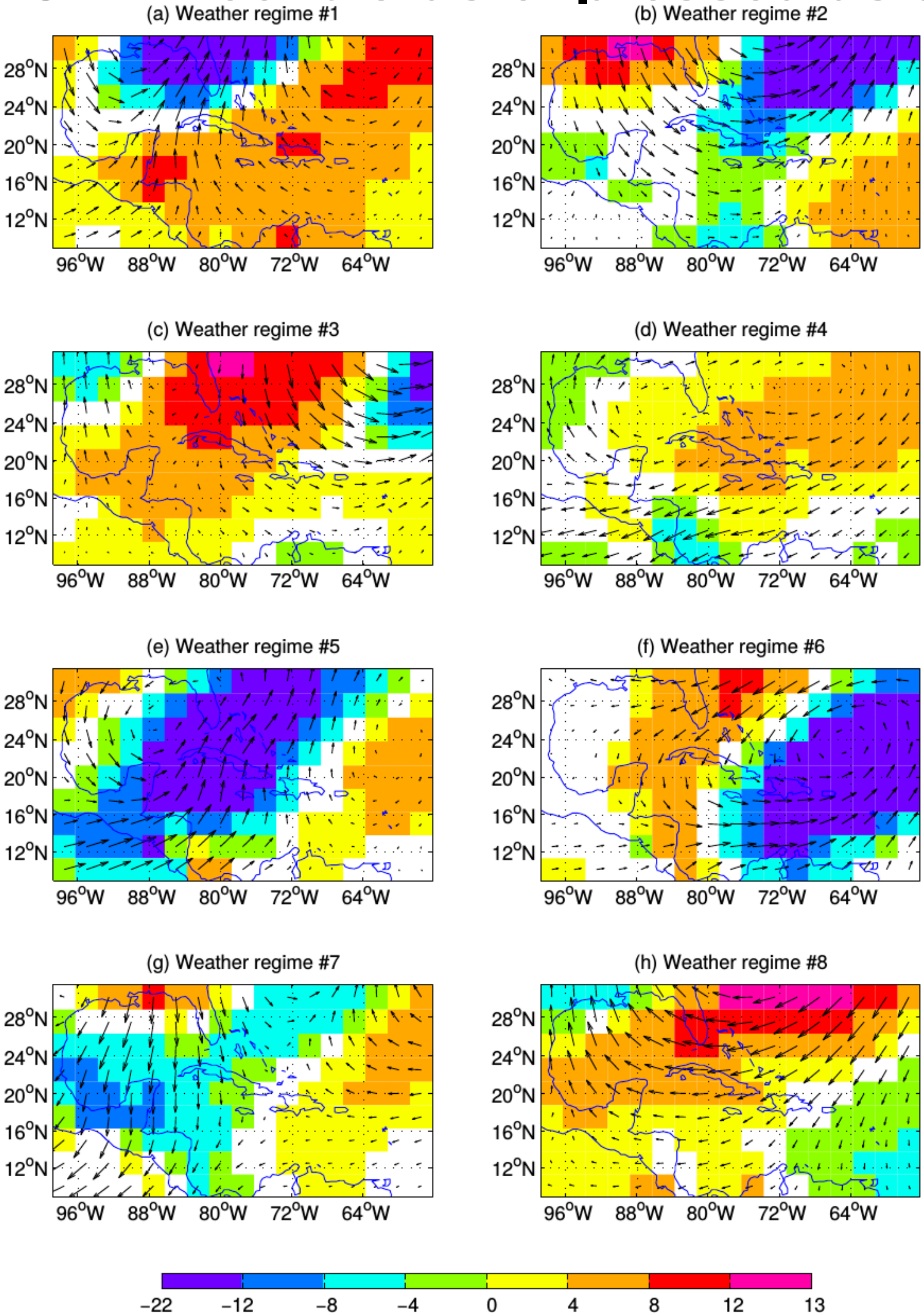


Centroids of the 8 Wts with OLR in color and 925 hPa winds as vectors (+ wind speed of 5, 7.5 and 10 m/s as gray contours) (Moron et al., 2015c)

Winter WTs (1-3 & 7-8) are mostly differentiated by (1) location of the trough's axis on the extratropical edge and (2) location of tropical anticyclone. It could be interpreted as snapshots of travelling synoptic waves and also longer features as cold surges (ex : WT# 7 ; Saenz and Durada-Quesada, 2015)

Summer WTs (4-6) ; WT 4 (= « trade » WT) is close to the climatological mean with strong tropical anticyclone, fast CLLJ and deep convection restricted over South America, Eastern Pacific and central America ; WT 5 – 6 are associated with reduced subsidence and CLLJ with two SW-NE band of deep convection over Western (WT 5) and Eastern (WT 6) Caribbean basin

3- WT centroids expressed as anomalies vs the annual cycle

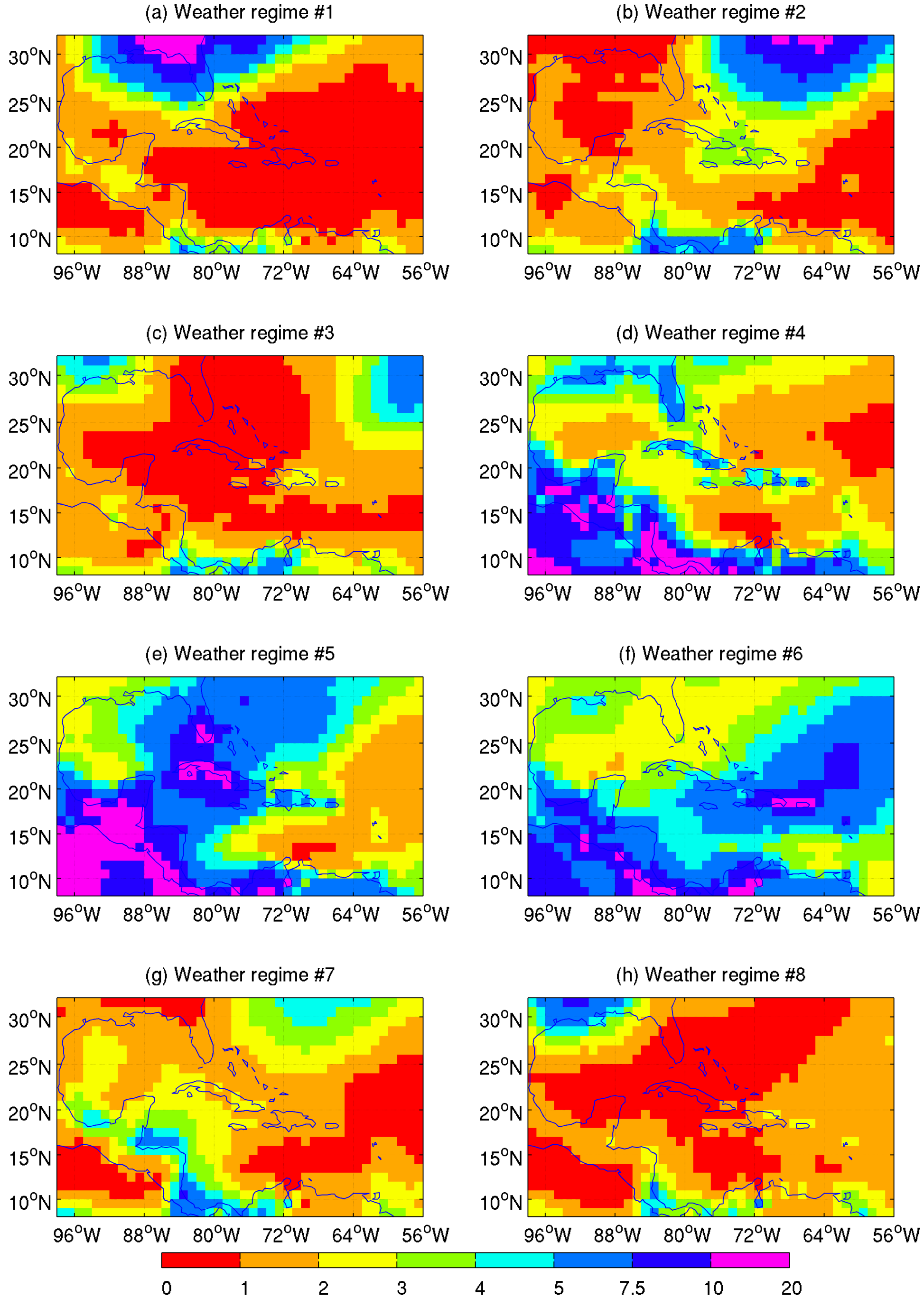


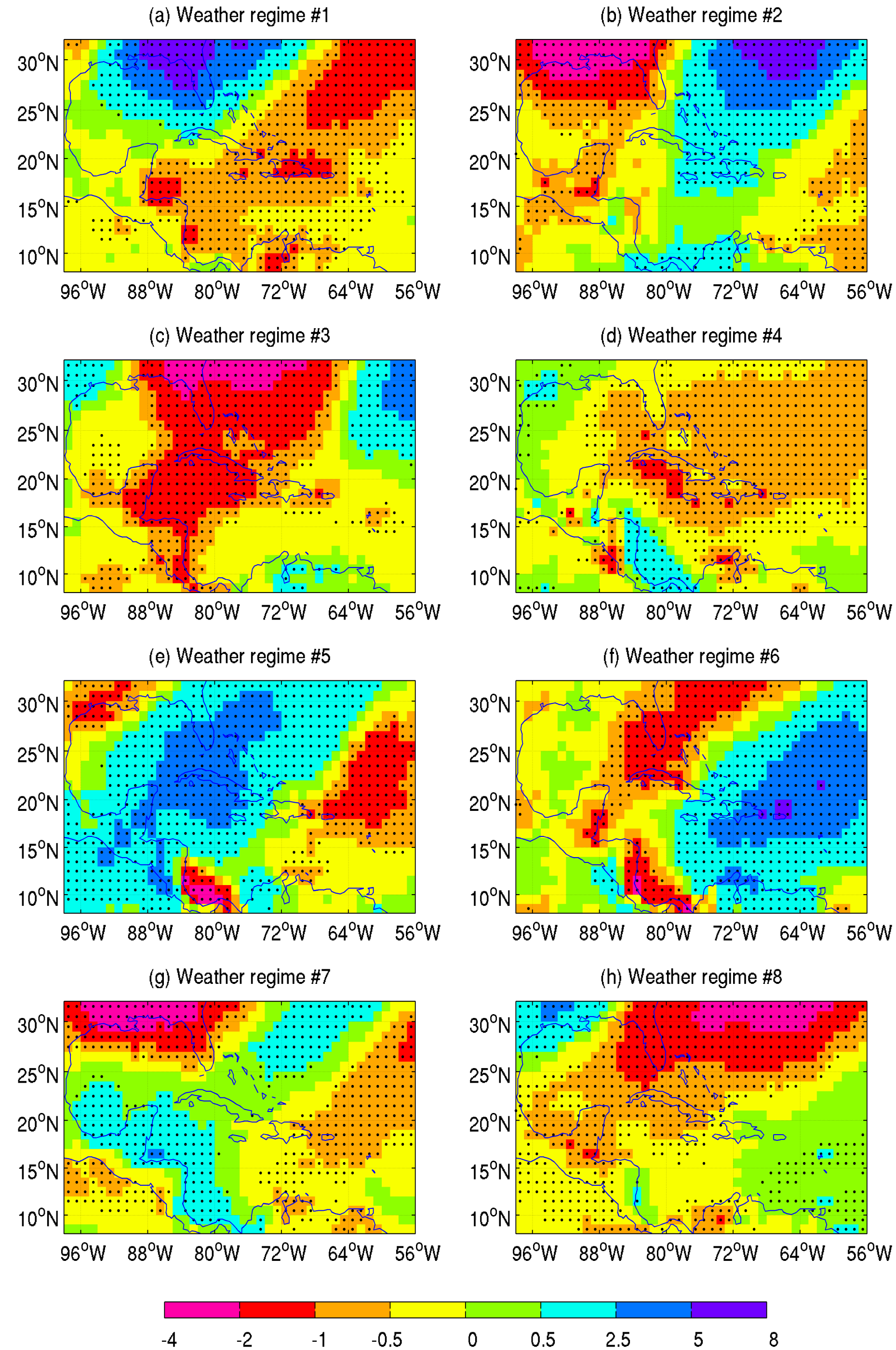
Centroids of the 8 Wts with OLR in color and 925 hPa winds as vectors expressed as anomalies vs the daily mean over 1979-2013 (Moron et al., 2015c). Colors (vectors) show significant OLR (wind) anomalies at the two-sided 95 % level)

Winter WTs (1-3 & 7-8) ; negative OLR anomalies match usually with southerly anomalies (i.e. ahead of extratropical troughs). Interaction between wind and geography are visible (negative OLR anomalies windward)

Summer WTs (4-6) ; WT 4 = increased subsidence over the whole Caribbean basin and increased anticyclonic flow (+ increased convection windward of Panama and Nicaragua Caribbean coasts) while WTs 5-6 are associated with a large cyclonic anomalies over Western and Eastern Caribbean basin

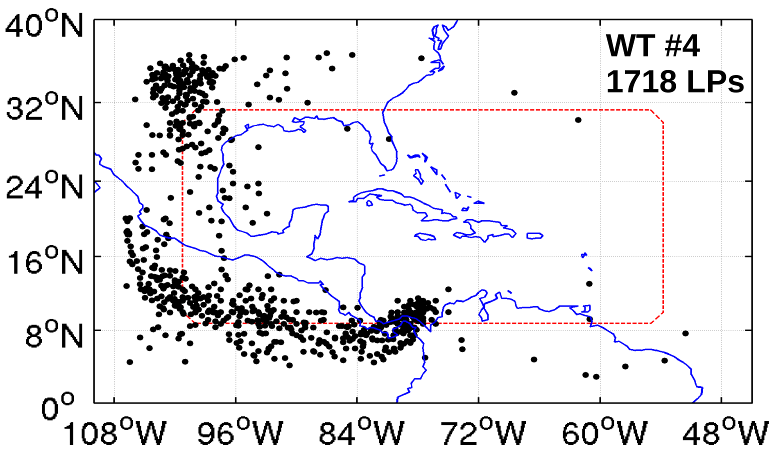
3- Mean rainfall and anomalies in WTs

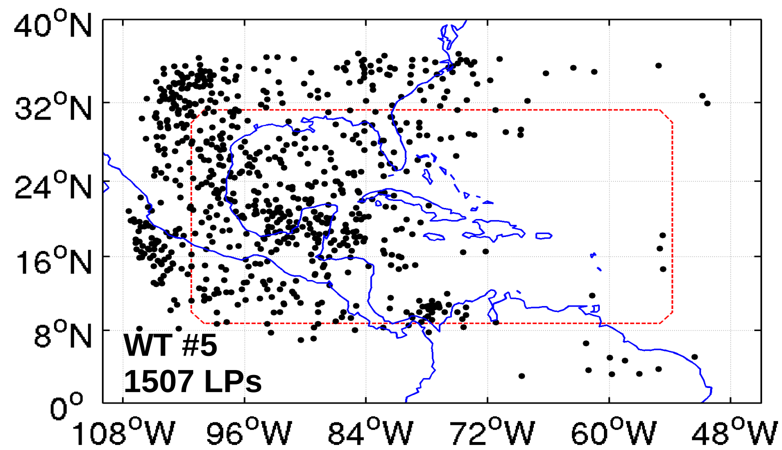


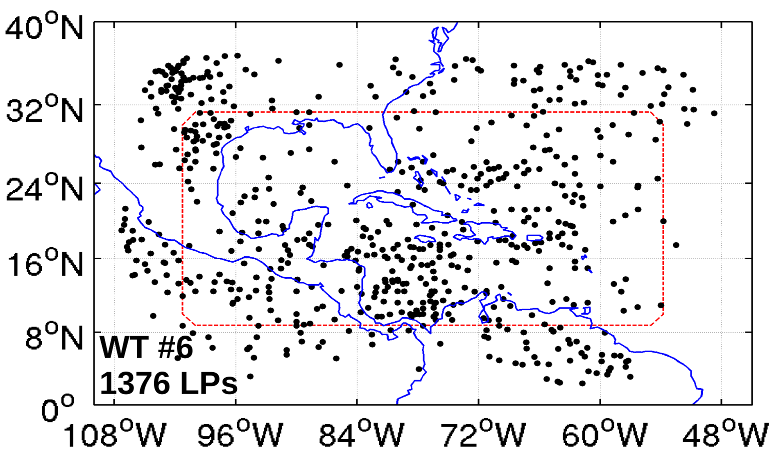


Raw (right) and anomalous (right) rainfall from GPCP (in mm/d) associated with the 8 WTs (Moron et al., 2015c). Dots (right panels) show significant anomalies at the two-sided 95 % level.

4- WTs vs synoptic and smaller phenomena in « Summer »



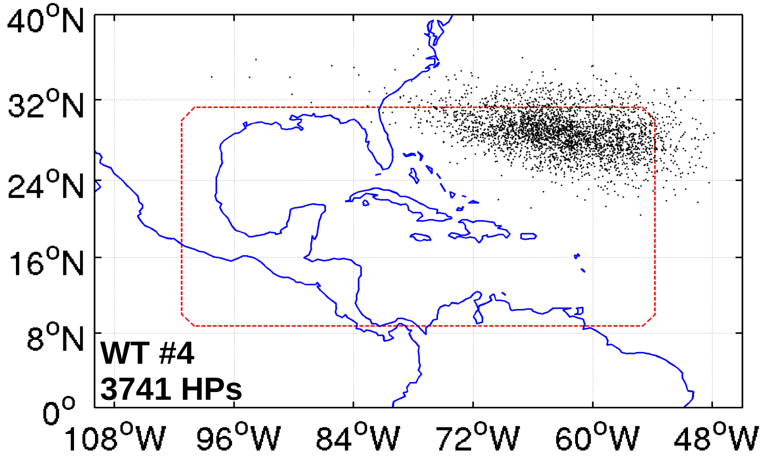


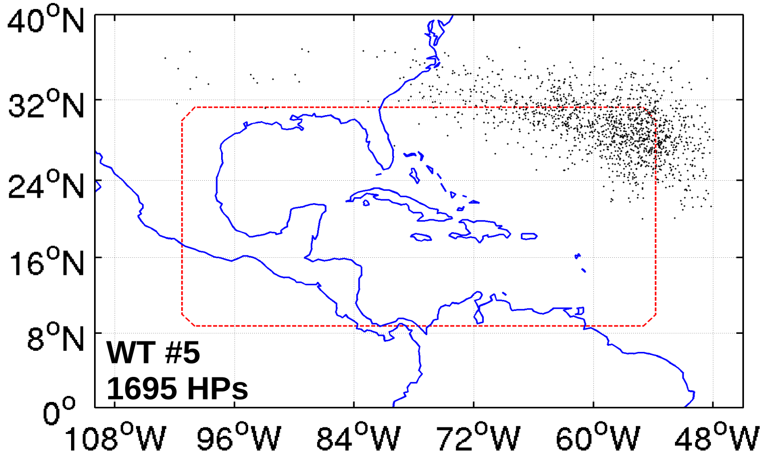


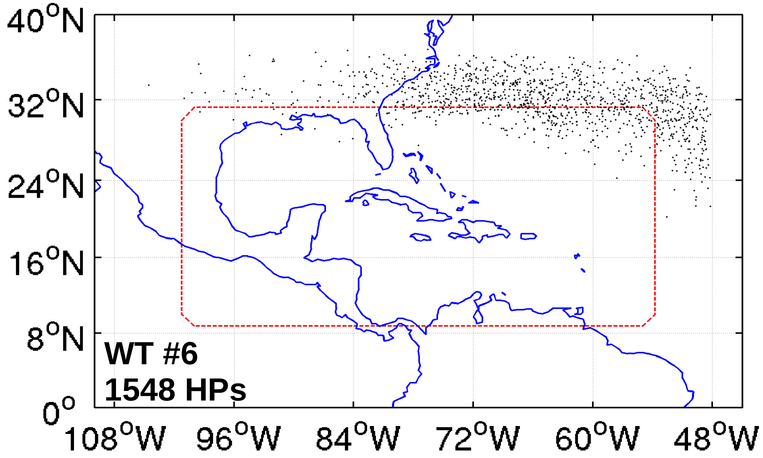
Centers of gravity of individual low pressure < 1009 hPa -LP- (only low pressures having at least one grid-point having a daily mean SLP < 1009 hPa inside the red contour are counted). An higher level than 1009 hPa tend to merge together different phenomena (as ITCZ and low pressure system over Texas through inter-America isthmus)

Even if WT are, by definition, unable to identify individual synoptic or mesoscale systems, they are able to detect the PDF of their locations. WT 4 = fewer LP than expected in summer, and LP heavily concentrated on Pacific ITCZ and Panama Bight + Texas ; WT 5 = LPs on Western Caribbean ; WT 6 = includes almost all LPs centered on Eastern Caribbean basin (E of 80°W)

4- WTs vs synoptic and smaller phenomena in « Summer »



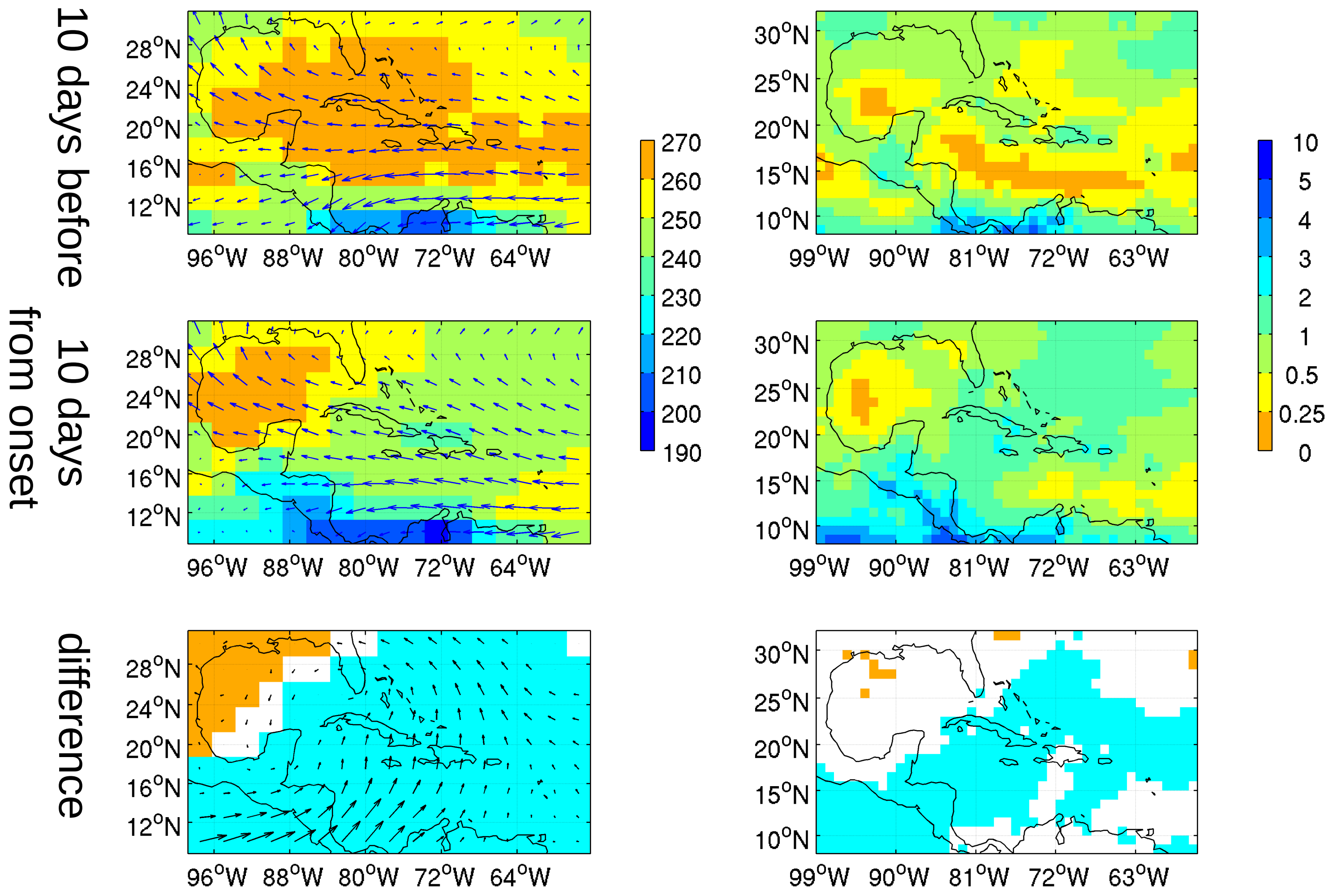




Centers of gravity of individual high pressure > 1017 hPa -HP- (only high pressures having at least one grid-point having a daily mean SLP > 1017 hPa inside the red contour are counted).

HP centers are closer to Caribbean basin (and slightly more abundant than expected by chance) and more concentrated on a small area in WT#4 than in WT#5 and WT#6

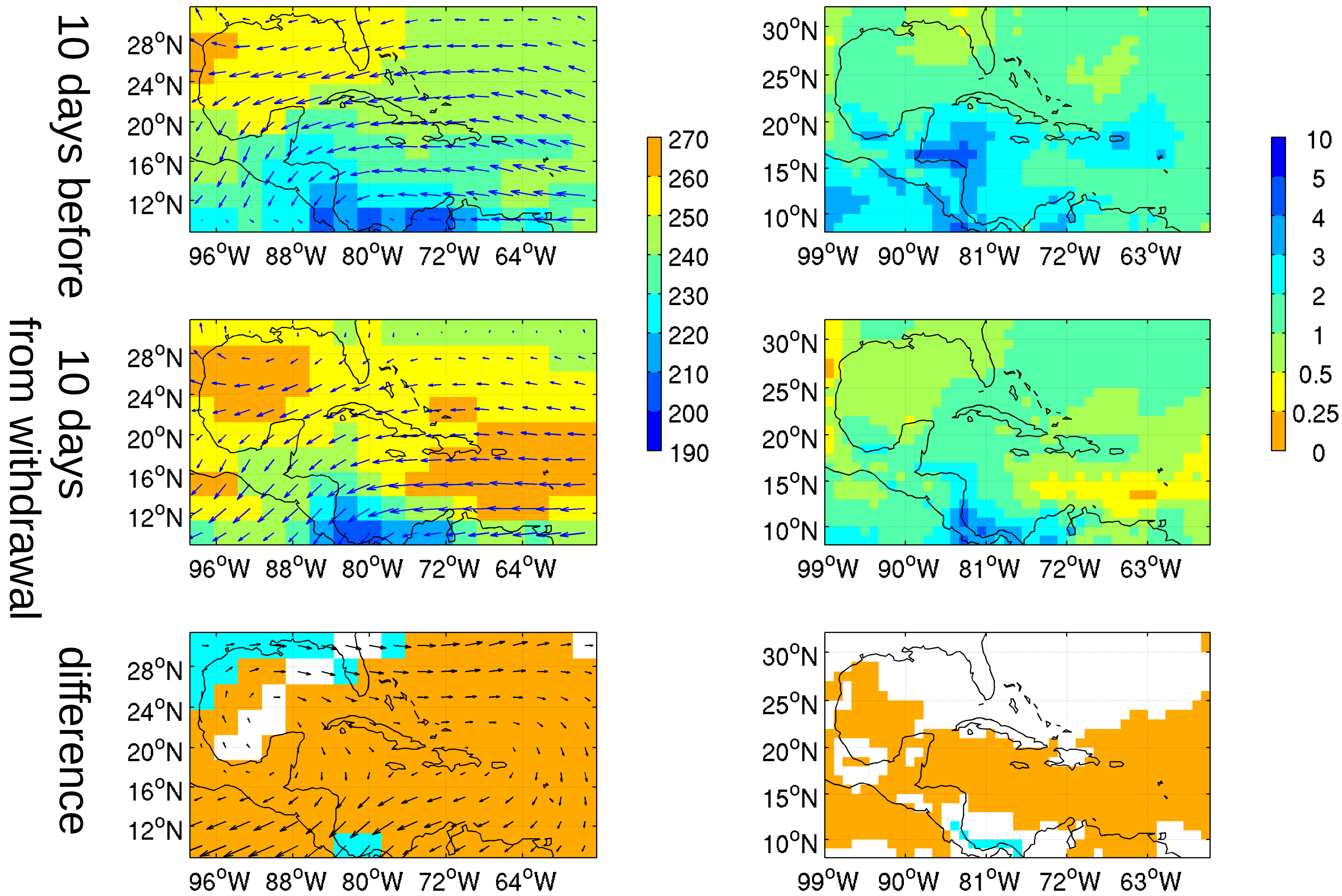
4- Regional-scale onset of « summer » defined from WT



Regional-scale onset of summertime conditions is defined as the first day of a 5-day spell of either WT#4, #5 or #6 without any of them in 5 consective days in a 30-day window thenafter. Mean date = May 9 (std = 8 days). The 925 hPa winds and OLR (left panels) and rainfall (right panels) are plotted on 10 days before and from the onset and the lower panels are the Student's T test of the difference between both 10-day periods)

Regional-scale onset ? A cyclonic anomaly on Gulf of Mexico associated with a clear **northward veering of the trades** over most of the Caribbean basin + **significant increase of local-scale rainfall and convection** across the basin. We'll return later to the potential predictability of the regional-scale onset

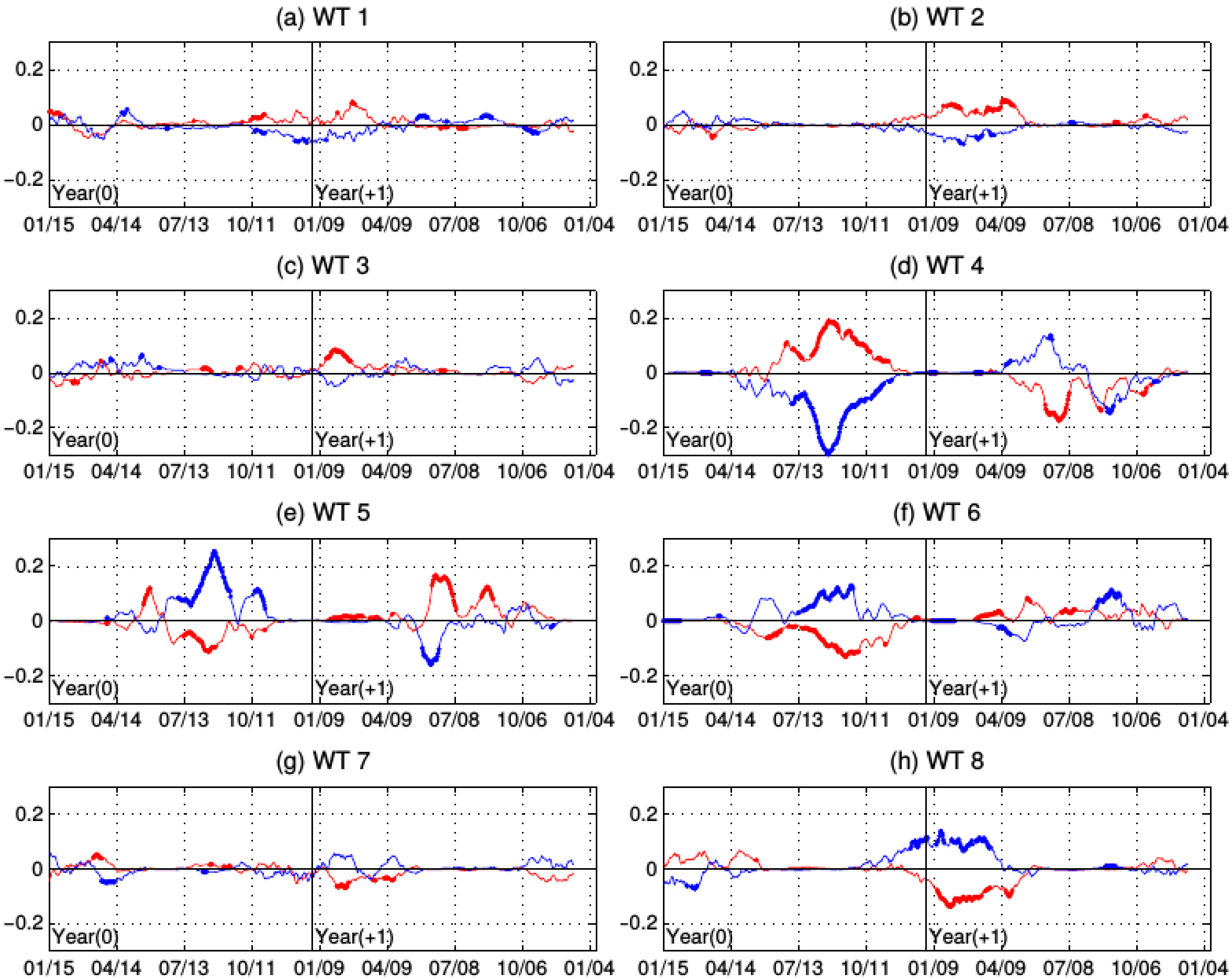
4- Regional-scale withdrawal of « summer » defined from WT



Regional-scale end of summertime conditions is defined as the last day of a 5-day spell of either WT#4, #5 or #6 without any of them in 5 consective days in a 30-day window before. Mean date = October 24 (std = 11.5 days). The 925 hPa winds and OLR (left panels) and rainfall (right panels) are plotted on 10 days before and from the onset and the lower panels are the Student's T test of the difference between both 10-day periods)

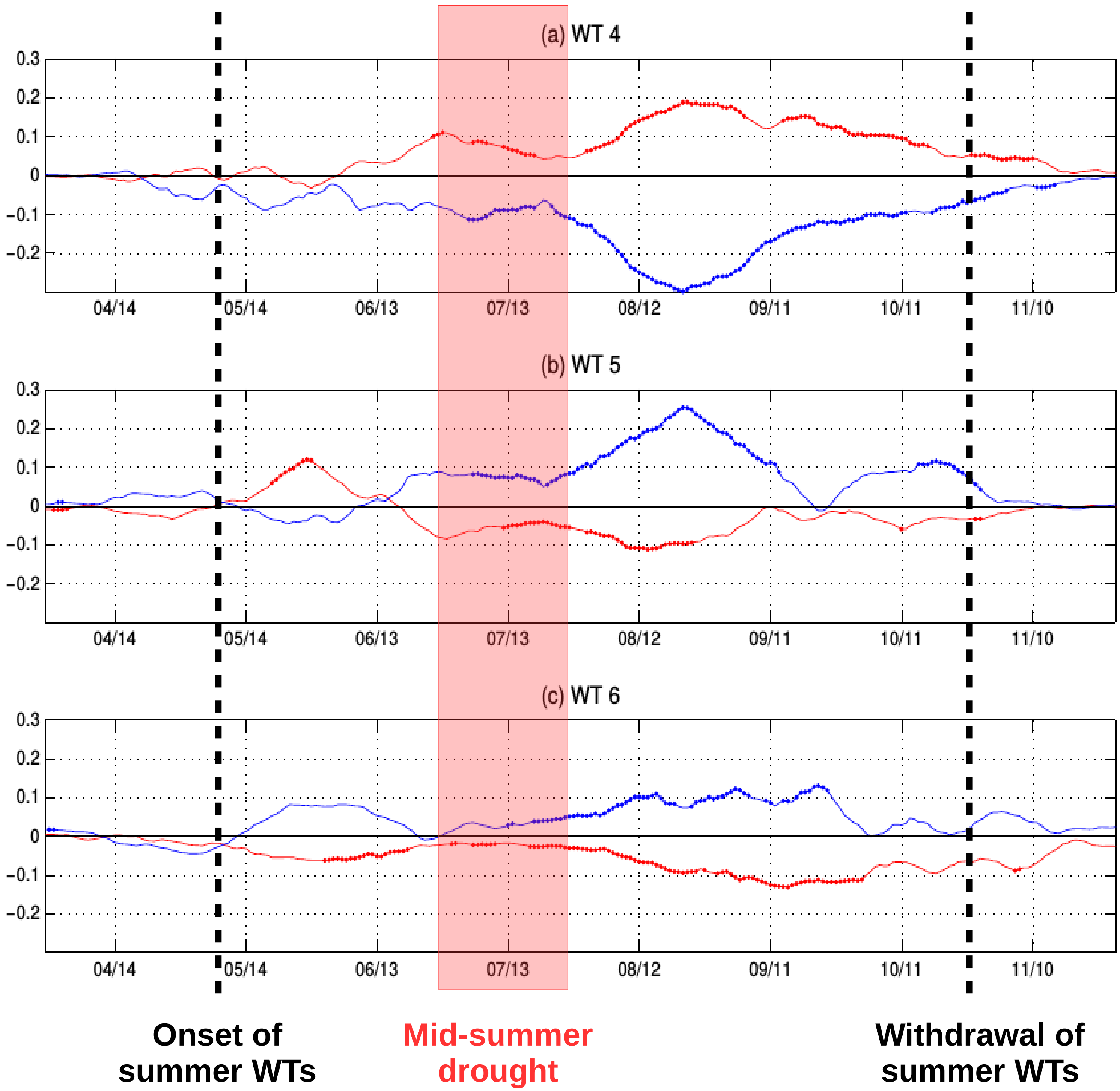
Regional-scale withdrawal ? Not exactly symmetric to onset ; increase of westerlies on the extratropical edges and increase of trades with a northerly component + clear increase of subsidence. Local-scale rainfall decreases everywhere except over the Caribbean coast of Panama (orographic forcing of N-NE winds)

5- The modulation of WT occurrence by ENSO (1)



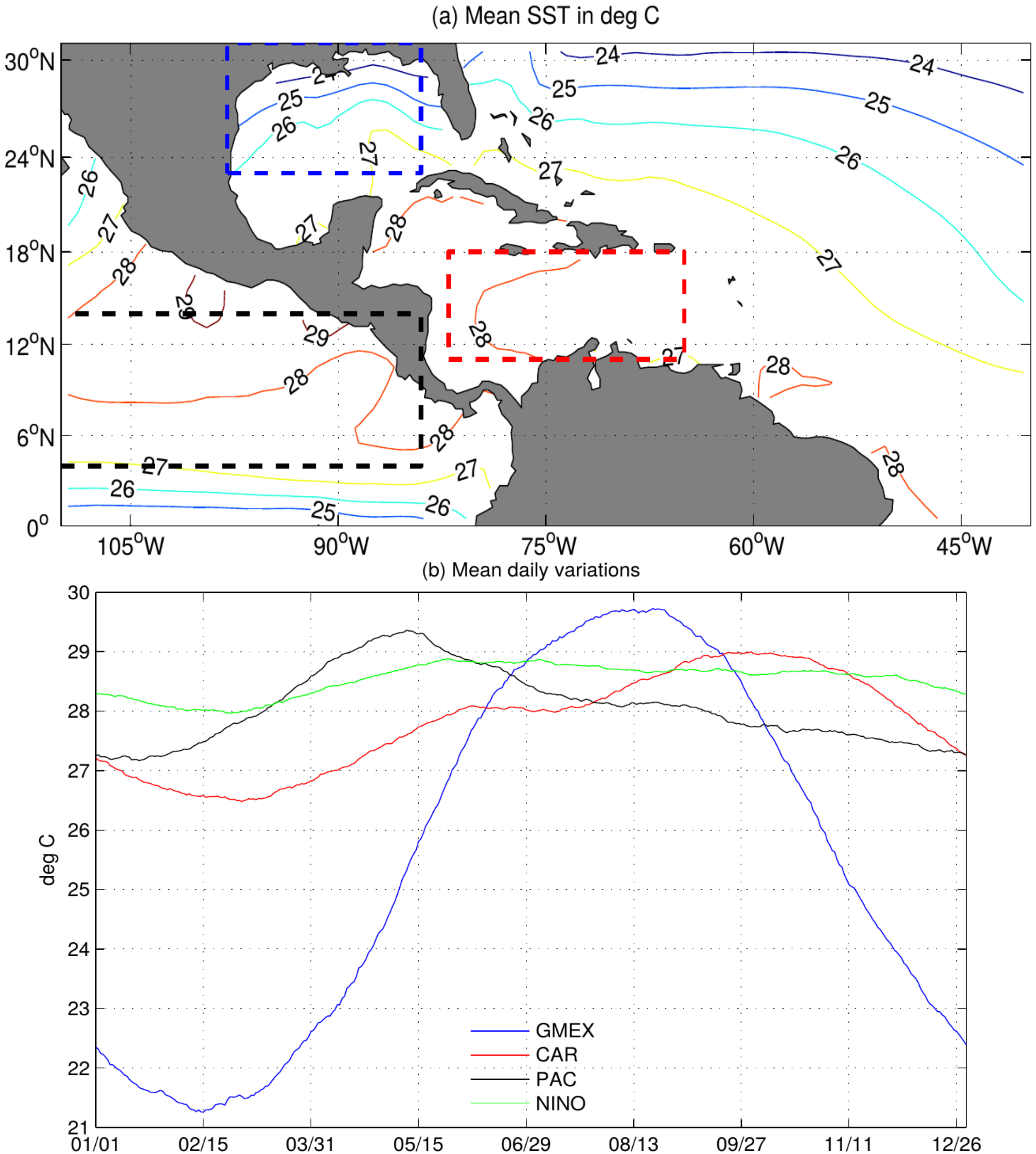
Mean anomalies of WT frequency across two years on running 31-day windows in association with warm and cold ENSO events (defined from SST anomalies averaged over 160°E-290°E, 5°N-5°S in October(0) – March (+1). The blue and red dots indicate significant anomalies at the two-sided 95 % level (Moron et al., 2015c)

5- The modulation of WT occurrence by ENSO (2)



Mean anomalies of WT 4-6 frequency across boreal summer of year(0) on running 31-day windows in association with warm and cold ENSO events (defined from SST anomalies averaged over 160°E-290°E, 5°N-5°S in October(0) – March (+1). The blue and red dots indicate significant anomalies at the 95 % level (Moron et al., 2015c)

5- Potential predictability of WT occurrence from SST

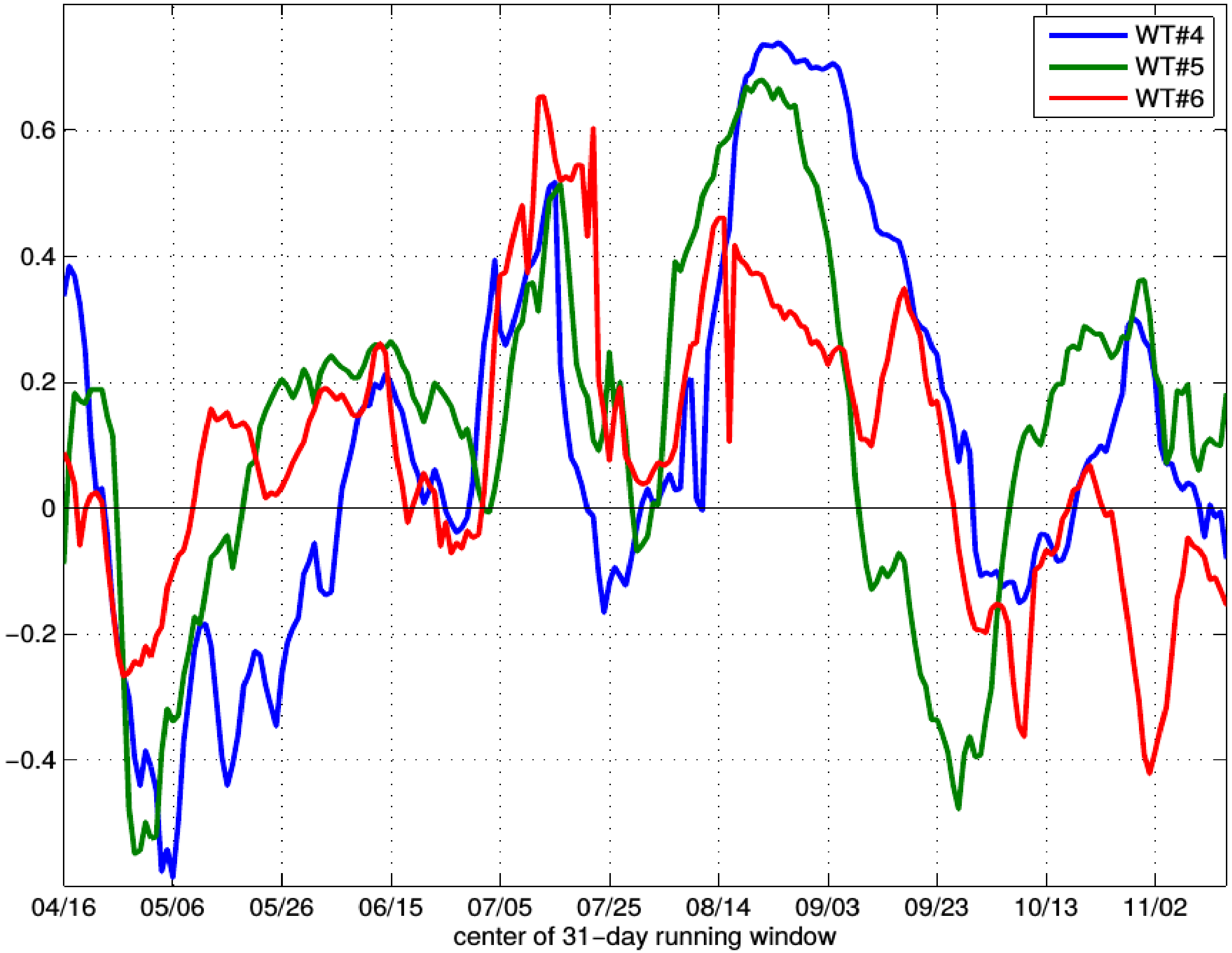


Mean annual sea surface temperature in °C with mean annual cycle of 4 regional-scale indices (NINO refers to Nino 3.4 box ; 190°-240°E, 5°S-5°N) (Moron et al., 2015c)

- PAC is warmer than CAR till late July, then colder to it
- GMEX is warmer than CAR from June to early October
- Regional-scale onset occur after when CAR is warmer than 27°C (in early April)

Logistic regressions (Guanche et al., 2014 ; Moron et al., 2015b) are constructed between the 4 indices and the WT memberships averaged over running 31-day window (with SST leading WT by 1 month ; for example SST from March 31 to April 30 with WT from May 1 to May 31 for the 31-day WTs)

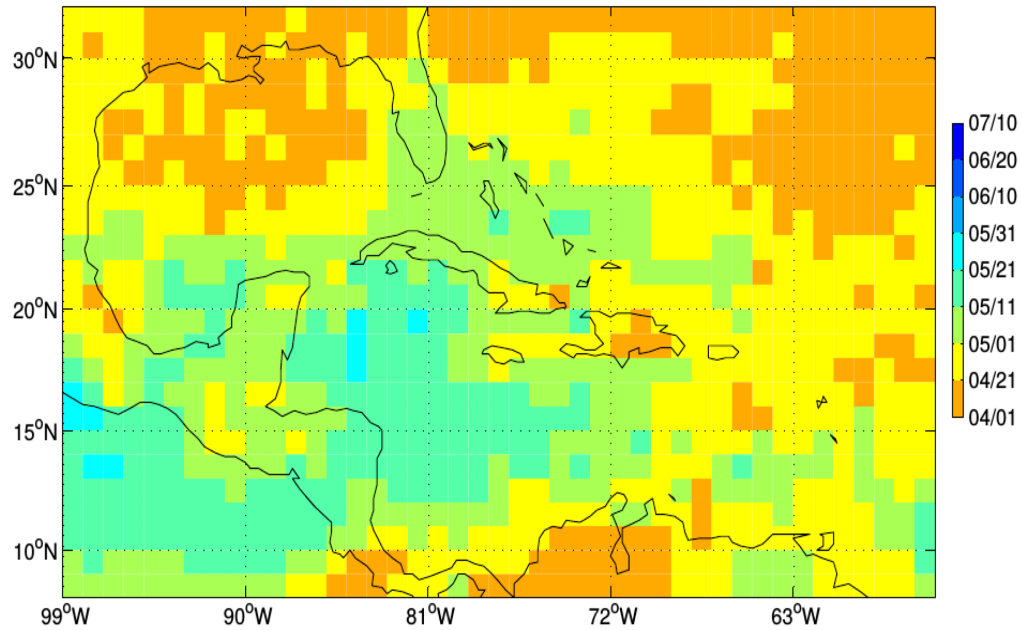
5-Potential predictability of summertime WTs from antecedent SST (31-day running windows)



Correlations between observed and simulated mean probability of WT 4-6 on 31-day running window. The predictions are done with a cross-validated (one year left out at each turn) multinomial logistic regression using the 4 SST indices (GMEX, CAR, PAC and NINO) one month before as predictors of WT probability

Skill is close to 0 at the start and close to the end of the « summertime » season, then peak at 0.4-0.7 in July (~ mid-summer drought – MSD-) and from mid-August to late September (~ during the second annual peak of rainfall). The transition between MSD and the second rainfall peak is less predictable

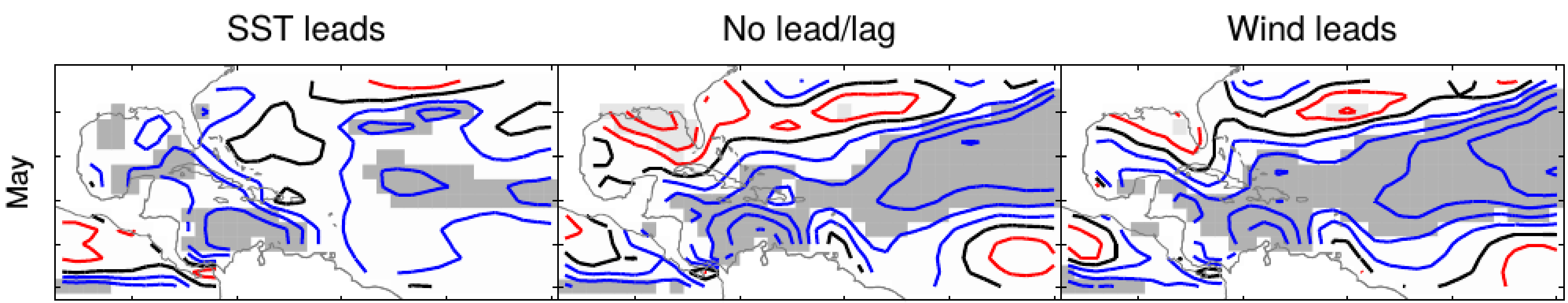
5- What are the sources of the WT occurrence ? the example of the onset (1)



Mean local-scale onset from daily GPCP data (Gouirand et al., in prep)

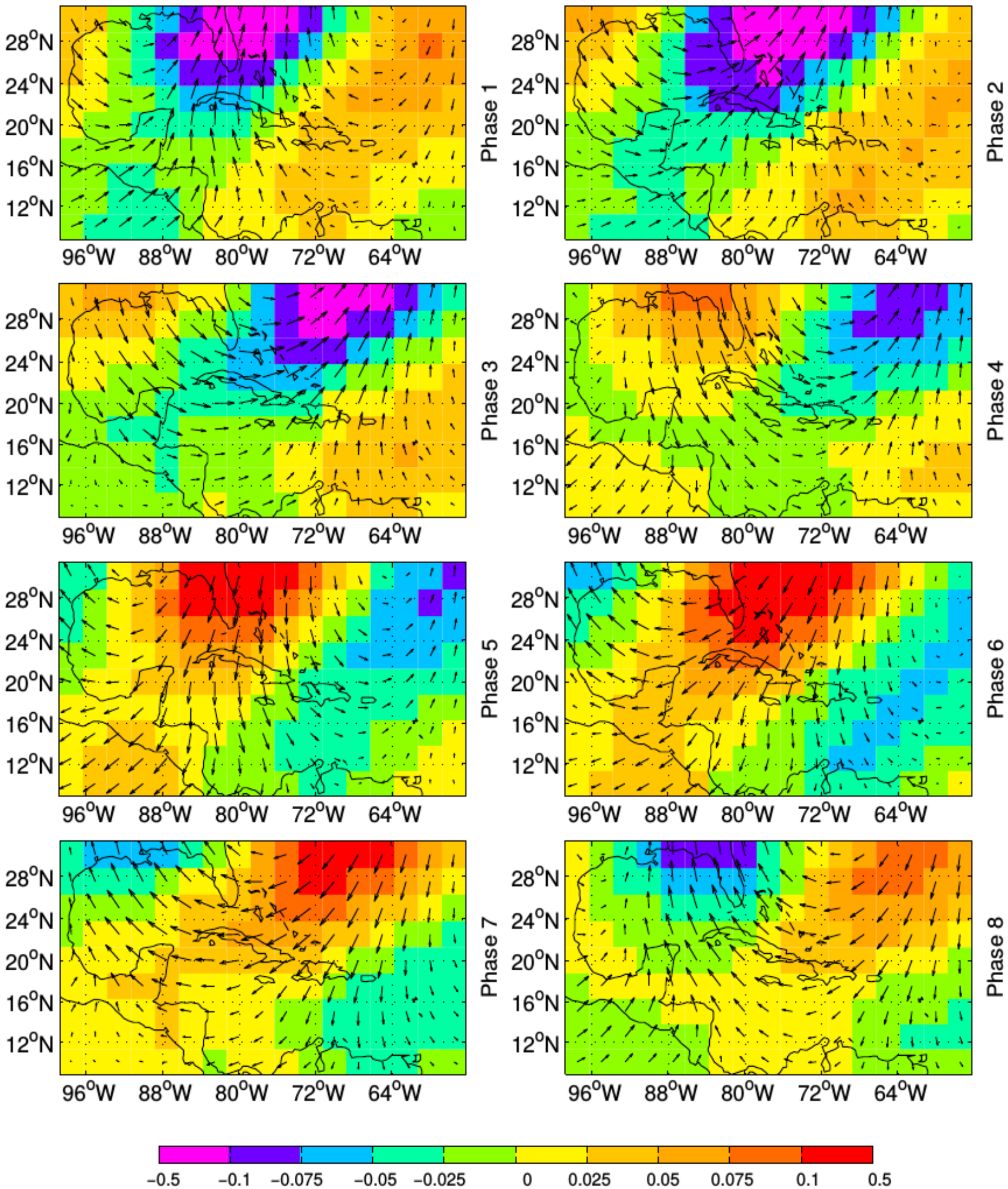
The abrupt transition from « winter » to « summer » WTs (May 9 in mean) is well phase-locked with the local-scale onset, is not very variable at interannual time scale, and is not predictable from local and remote anomalous SST

In May, the forcing of local wind speed on local SST (i.e. increased wind speed = cooling) is more intense than the reverse feedback



Local correlations between SST and wind speed in May (SST leads by one month on the left panel and follows by one month on the right panel ; the middle panel is for zero lag). Contour interval is 0.1 with zero correlation = black contour (positive corr. = red contour) (Moron et al., 2015a)

5- What are the sources of the WT occurrence ? the example of the onset (2)

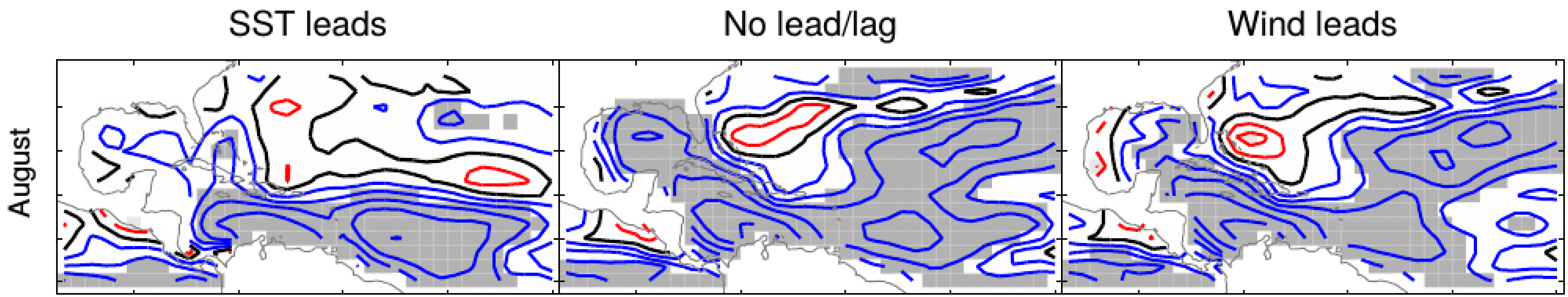


Reconstruction of a 15-20 day oscillation from a M-SSA of OLR and 925 hPa winds in March-June only. Composite anomalies (OLR in shadings and 925 hPa winds as vectors) are computed on 8 phases of the 15-20 day quasi-oscillation

The regional-scale onset of summertime conditions (from WT) occurs mostly in phases 8, 1 and 2 (22 cases out of 35) and almost never occur in phases 3 and 4 (1 case out of 35)

Hypothesis :
Regional-scale onset of summertime conditions is a combination of the periodic annual solar forcing (>> slow warming of inner seas and northward shift of the ITCZ till northern South America and Eastern Tropical Pacific) + stochastic atmospheric forcing associated with a wavetrain in the middle latitudes (which tend to synchronize the local-scale onset). The **predictability is perhaps limited to intraseasonal time scale**

5- What are the sources of the WT occurrence ? the example of the second part of the rainy season



Local correlations between SST and wind speed in August (SST leads by one month on the left panel and follows by one month on the right panel ; the middle panel is for zero lag). Contour interval is 0.1 with zero correlation = black contour (positive corr. = red contour) (Moron et al., 2015a)

The occurrence of WT 4-6 is partly predictable from SST (at least when local and Eastern Pacific SST are taken into account). Anomalous cold SST on the Caribbean basin associated with anomalous warm SST on the Eastern Tropical Pacific) lead to more (less) WT 4 (WT 5 and 6)

Hypothesis :
The local air-sea coupling is able to sustain OA anomalies through positive feedback, i.e. faster CLLJ (favoured in WT 4) cool the south of the Caribbean basin and this anomalous cooling tends to increase the CLLJ by increasing zonal (meridional) thermal gradient with Eastern Tropical Pacific (Gulf of Mexico).

It remains to understand the interaction between WT occurrence and 3-9 day variability (easterly waves ?) to see if WT 5 and 6 could be mostly interpreted (or not) as different phases of similar atmospheric phenomenon

6- Concluding remarks (1)

- Due to large dimensions of atmospheric variability and weak evidence (if any) of multimodality, WTs should not be necessarily considered as empirical estimates of unknown dynamical attractors but rather as a data-adaptative filter of the complex atmospheric variations
- The WT filtering works through the emphasizing of the largest scales (through pre-processing EOF and the selection of the most recurrent patterns) and also the reduction of transient and unreproducible features, i.e. any meteorological events which are too scarce and/or erratic and/or too small in extent and/or not reproducible in time
- It is a different, but complementary, approach, of the *a priori* bandwidth filtering to emphasize a specific time scale (as a bandpass filter between 20 to 90 days to emphasize the intraseasonal variations). The retained bandwidth by WT is defined by the data themselves and is indeed very large
- In that context, parameters as the « optimal » number of WT is not a serious issue : Saénz and Duran-Quesada (2015) and Chadee and Clarke (2015) analyzing the same area using different sets of variables found 11 and 7 WTs … but their interpretation is very close to ours. The « optimal » number is the one that allows a physical interpretation of the resultant WT and our choice is perhaps a lower threshold (a larger number will allow for example to extract different stages of travelling waves)

6- Concluding remarks (2)

- WT, when defined without removing the annual cycle, includes all time scales beyond transient synoptic and meso-scales. Even these shorter time scales are someway included through their reproducible characteristics (i.e. their tracks and/or occurrence and/or amplitude if they are systematically modulated by WT occurrence) through the WT prism
- In the Caribbean basin, the main distinction of the WT clustering is the differences between the « wintertime » and « summertime » WTs with an abrupt transition from « winter » to « summer » in early may and a more gradual transition between summer and winter in late October. Both transitions seem not SST-forced
- Winter WTs ? They mostly reflects the axis of travelling troughs on the extratropical edge (but also intensity of the eastern Pacific ITCZ and long-lasting cold surges)
- Summer WTs ? Mostly an opposition between a « trade » regime (WT 4) with fast CLLJ and regional-scale subsidence over the whole Caribbean basin + strong ascendance over the Eastern Pacific ITCZ and two « cyclonic » regime including cyclogenesis over the Caribbean basin (Western Caribbean basin in WT 5 and Eastern Caribbean basin in WT 6)
- WT 4 is almost exclusive during the Mid-Summer Drought (in July), which could be interpreted as the stable summertime atmospheric situation across the Basin. This situation is perturbed by WT 5 and 6

6- Concluding remarks (3)

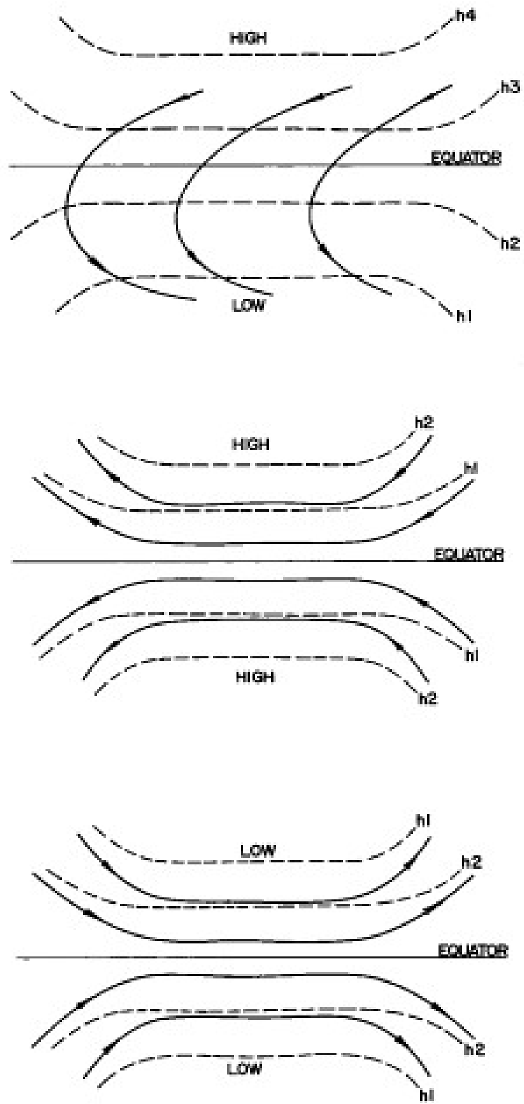
- Preliminary trials show that predictability provided by SST is very weak around the early stage of summer conditions, then increase toward its end with a transient decrease between the MSD and the second peak of the rainy season
- The regional-scale onset from WT perspective around May seems to be a combination of two different forcings ; (1) the annual cycle of solar radiation warms the inner seas and pushes ITCZ northward (over the Eastern Tropical Pacific and the northernmost South America) ; (2) the stochastic forcing associated with an atmospheric wavetrain on the northern edge of the domain (with a quasi-periodicity of 15-20 days). In consequence, the regional-scale onset, while spatially consistent and tightly synchronized across the basin, would not be predictable from SST forcing
- The predictability from SST peaks during the second phase of the rainy season, partly because the ocean-atmosphere coupling allows positive feedback between the SST anomalies and wind speed of the CLLJ, over the Caribbean sea. The increasing amplitude of ENSO events during the year (0) could also provide some predictability from remote central and eastern Tropical Pacific
- These examples illustrate the ability of WT to encapsulate different phenomena occurring at various spatial and temporal scales. WTs provide also some relevant information about systematic modulation of small scales of motion

7- References

- Chadee XT, Clarke RM (2015) Daily near-surface large-scale atmospheric circulation patterns over the wider Caribbean. Clim Dyn, 44, 2927–2946.
- Diday E, Simon JC (1976) Clustering analysis. In: Fu KS (ed) Digital pattern recognition (communication and cybernetics), vol 10. Springer, Berlin, pp 47–94
- Ghil M, Robertson AW (2002) "Waves" vs. "particles" in the atmosphere's phase space: a pathway to long-range forecasting ? Proc Natl Acad Scin 99, 2493–2500.
- Guanche Y, Minguez R, Méndez FJ (2014). Autoregressive logistic regression applied to atmospheric circulation patterns, Clim Dyn, 42, 537–552.
- Johnson DH, Mörth HT (1960) Forecasting research in East Africa. Proc. Symp. on Tropical Meteorology in Africa, Nairobi, Kenya, World Meteor. Org./Munitalp Foundation, 56–132
- Lamb HH (1972) British Isles Weather types and a register of daily sequence of circulation patterns, 1861-1971. Geophysical Memoir 116, HMSO, London, 85pp
- Lorenz EN (1963) Deterministic nonperiodic flow. J Atmos Sci, 20, 130-141.
- Michelangeli RA, Vautard R, Legras B (1995) Weather regimes: recurrence and quasi-stationarity. J Atmos Sci, 52, 1237–1256.
- Moron V, Robertson AW, Ward MN, Ndiaye O (2008) Weather types and rainfall over Senegal. Part I: observational analysis. J Clim, 21, 266–287.
- Moron V, Frelat R, Jean-Jeune PK, Gaucherel C (2015a) Interannual and intra-annual variability of rainfall in Haiti (1905–2005). Clim Dyn, 45, 915-932.
- Moron V, Robertson AW, Qian JH, Ghil M (2015b) Weather types across the Maritime Continent: from the diurnal cycle to interannual variations. Front Environ Sci, 2, 65. doi:10.3389/ fenvs.2014.00065
- Moron V, Gouirand I, Taylor M (2015c) Weather types across the Caribbean basin and their relationships with rainfall and sea surface temperatures. Clim Dyn. Doi:10.1007/s00382-0.15-2858-9
- Pohl, B, Camberlin P, Roucou P (2005) Typology of pentad circulation anomalies over the Eastern Africa – Western Indian ocean region, and their relationship with rainfall. Clim Res, 29, 111–127.
- Sáenz F, Durán-Quesada AM (2015) A climatology of low level wind regimes over Central America using a weather type classification approach. Front Earth Sci, 3, 15. doi:10.3389/feart.2015.00015

Additional slide (1)

86 3 SYNOPTIC COMPONENTS OF MONSOONS



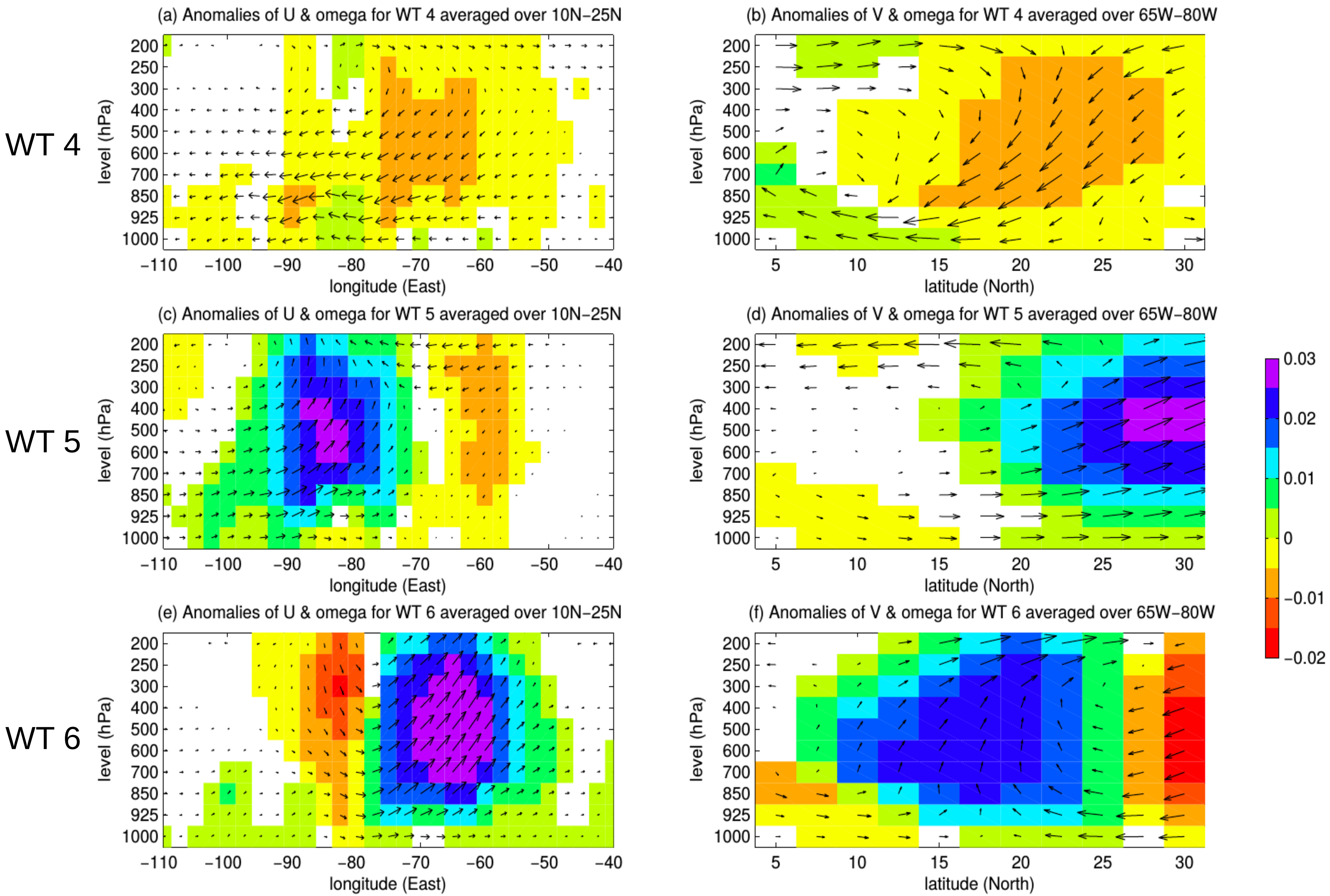
A trans-equatorial « drift »

An equatorial « duct »

An equatorial « bridge »

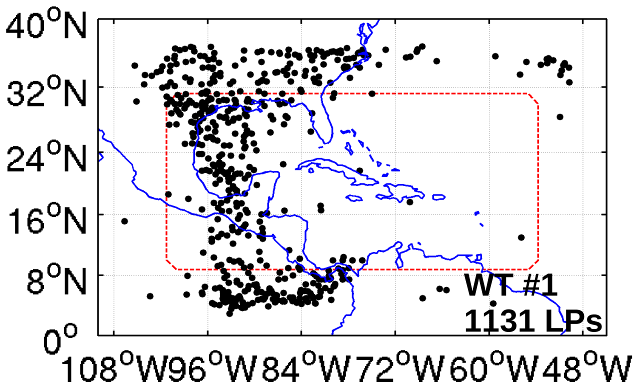
Fig. 3.33. Schematic representations of pressure distribution and flow associated with three equatorial circulation patterns (Johnson and Mörth, 1960). Full lines represent stream lines, dashed lines represent pressure-height contours. (Top) cross-equatorial "drift"; (middle) equatorial "duct"; (bottom) equatorial "bridge."

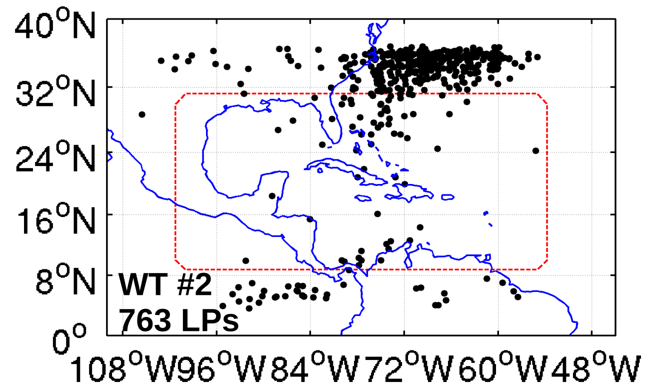
Additional slide (2)

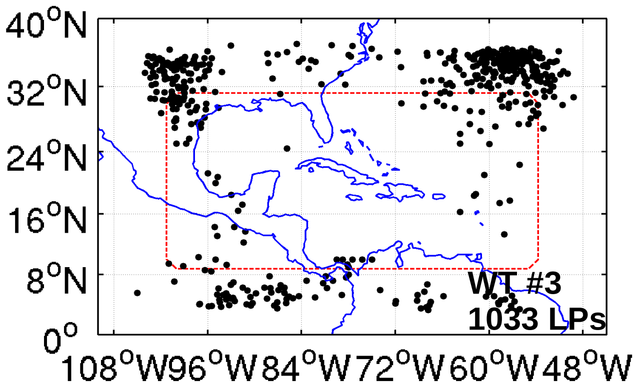


Longitude- (right) and latitude- (left) altitude cross sections of vertical wind (color) and zonal (right) and meridional (left) winds as vectors as anomalies vs daily mean for the summertime WT 4-6

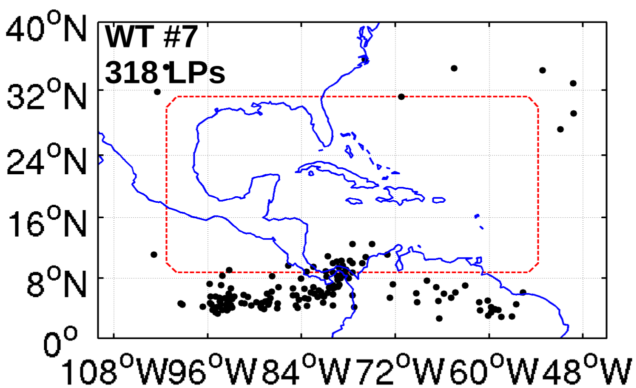
Additional slide (3)

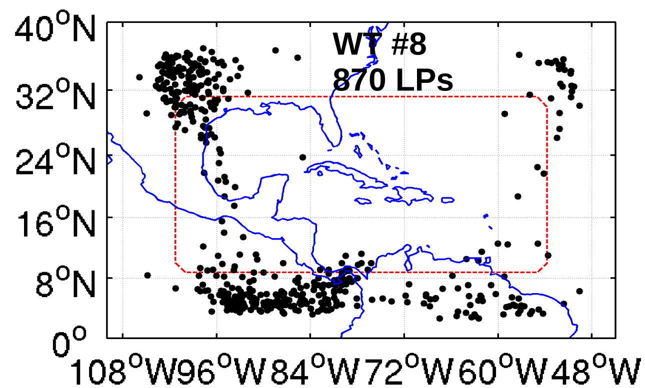






Centers of gravity of individual low pressure < 1009 hPa -LP- (only low pressures having at least one grid-point having a daily mean SLP < 1009 hPa inside the red contour are counted)

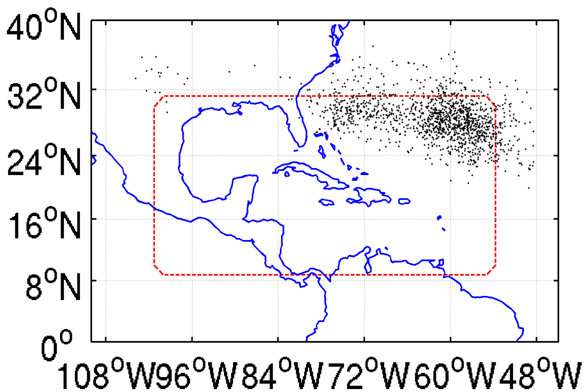




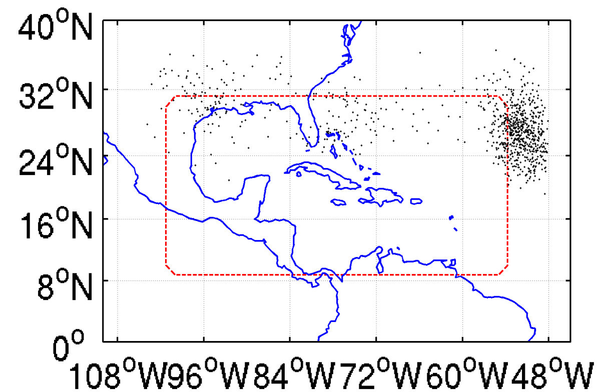
WT ~ axis of extratropical troughs (+ Pacific ITCZ) but also ~ tropical-extratropical interactions (mostly in WT#1 and WT#8)

Additional slide (4)

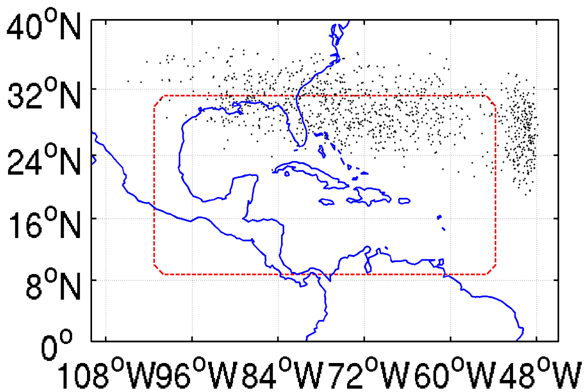
WT 1



WT 2

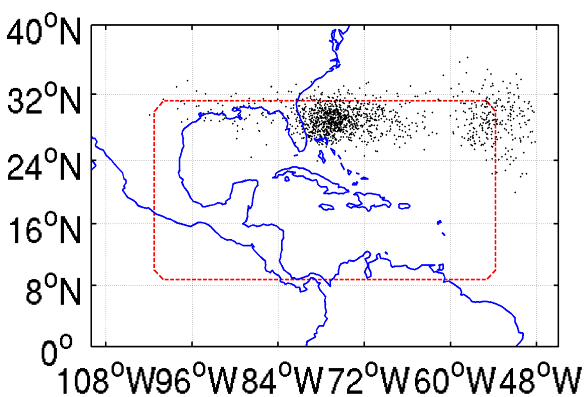


WT 3

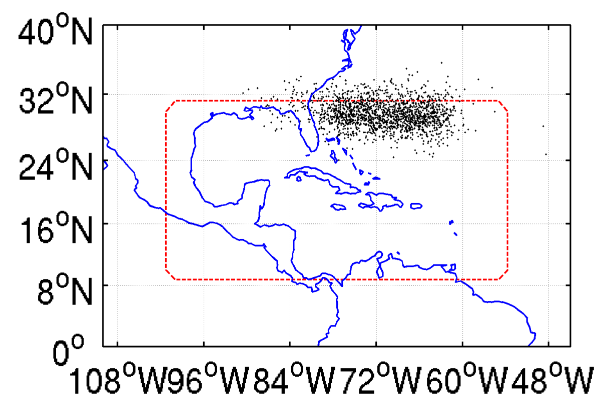


Centers of gravity of individual high pressure > 1017 hPa -HP- (only high pressures having at least one grid-point having a daily mean SLP > 1017 hPa inside the red contour are counted) for the 5 wintertime WTs

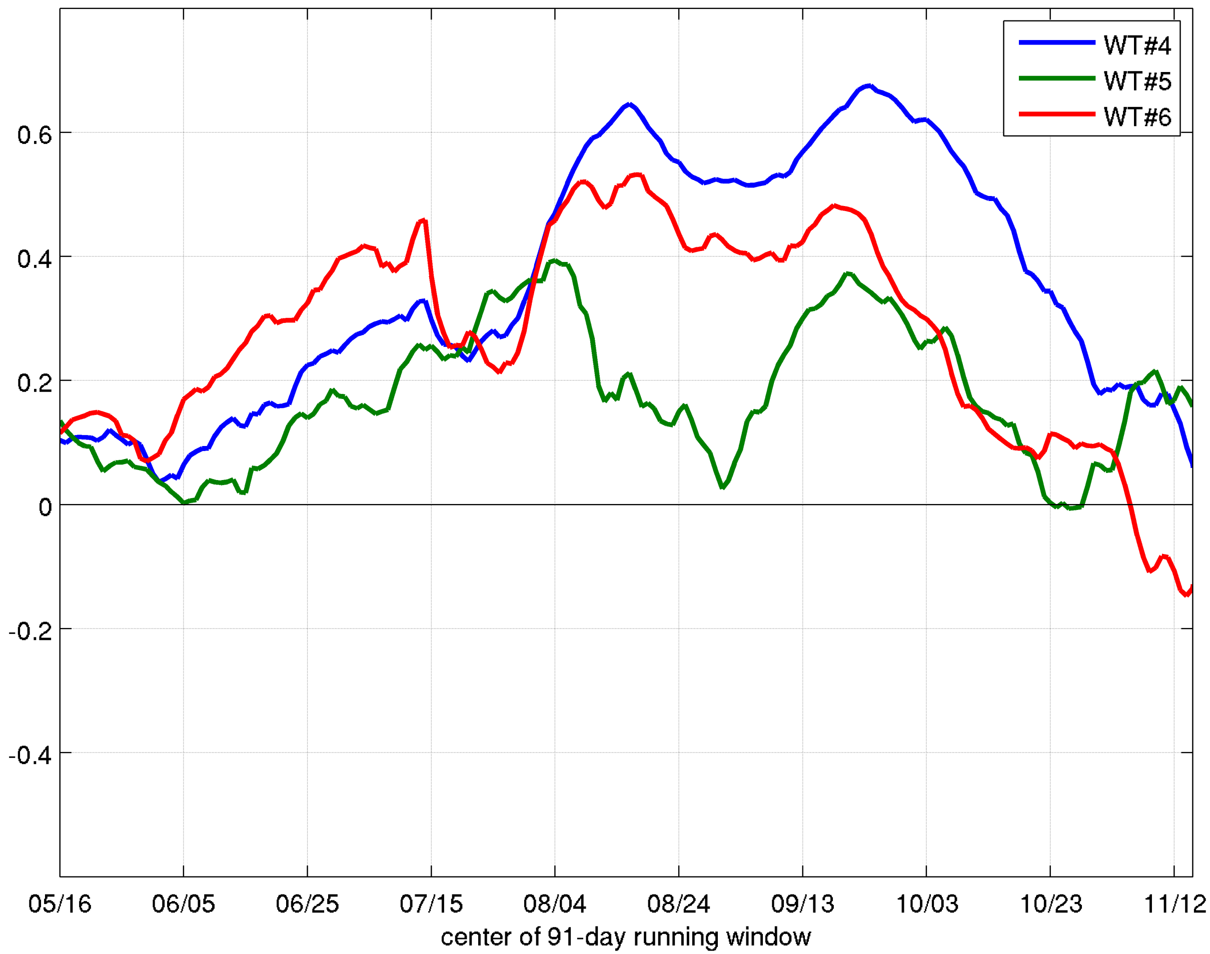
WT 7



WT 8



Additional slide (5)



Correlations between observed and simulated mean probability of WT 4-6 on 91-day running window. The predictions are done with a cross-validated (one year left out at each turn) multinomial logistic regression using the 4 SST indices (GMEX, CAR, PAC and NINO) one month before as predictors of WT probability

Skill is maximum during the second part of the summer, i.e. August-October, and the predictability is better for the trade regime (i.e. WT 4) than for the cyclonic regimes (i.e. WT 5-6)