Storm types across India : definition, characteristics and predictability

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Vincent Moron (moron@cerege.fr),
Renaud Barbero, Hayley J. Fowler,
Vimal Mishra & Andrew W. Robertson

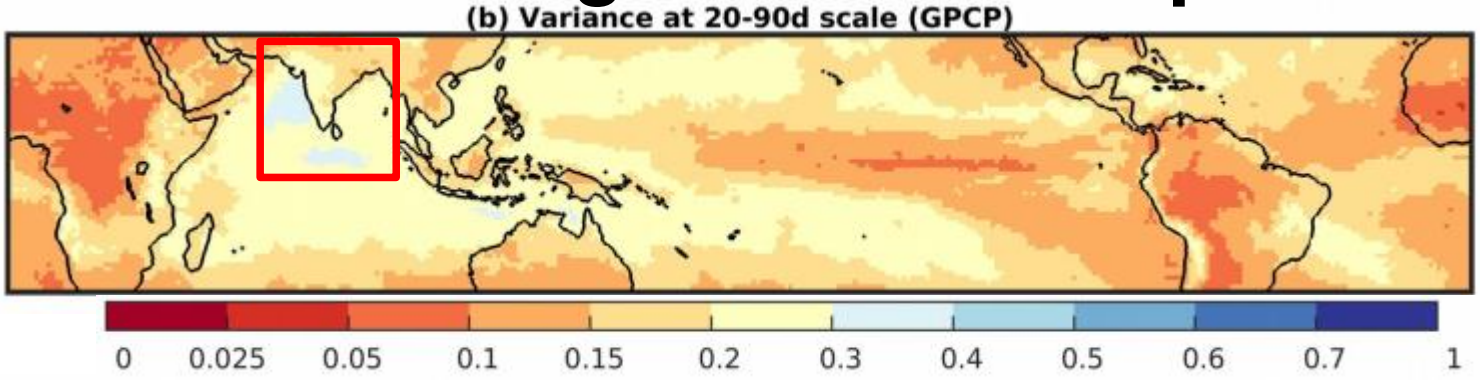
Tropical rainfall is a multiscale process from unitary cumulo-nimbus (Cb) to planetary-scale monsoon and quasi-divergent circulations, operating from the diurnal cycle to interannual-interdecadal scales

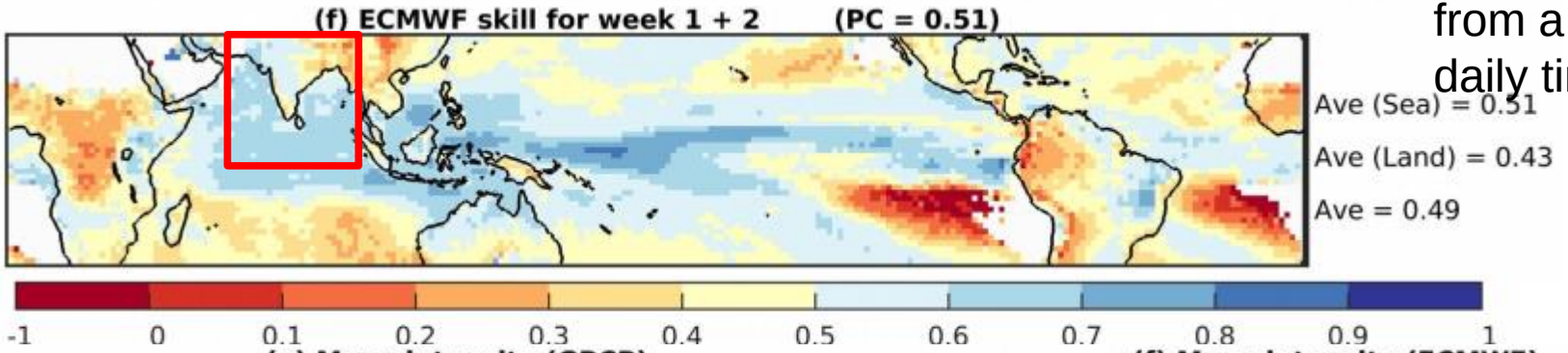
Prediction/predictability studies consider usually **time-averaged or filtered quantities at regional scales** to smooth some of the unpredictable « noise » related to small-scale processes and enhance the predictable « signal » related either to quasi-periodic atmospheric waves (CCEW, MJO, BSISO) and to ocean-atmosphere coupled phenomenon as ENSO, IOD ;

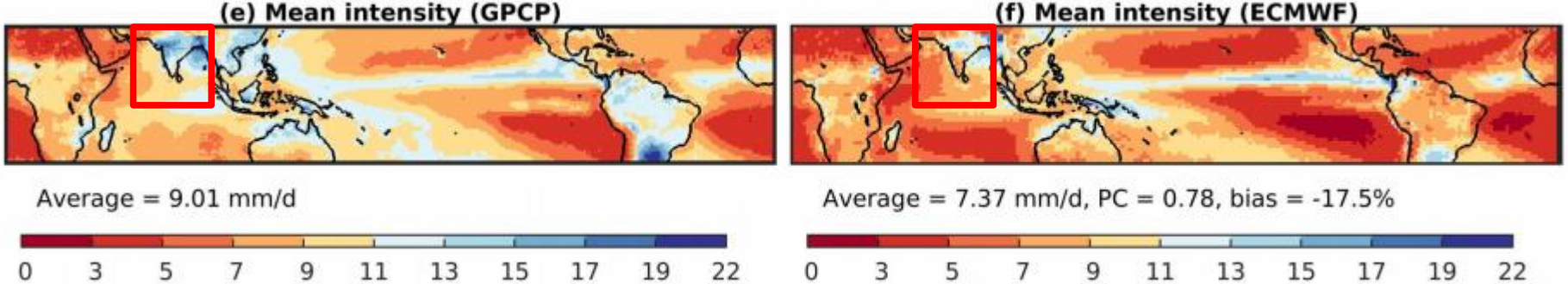
- The timescale filtering through averaging may be **insufficient to filter out the impact of extreme local-scale events, rather frequent across India** (Stephenson et al. 1999).
- Such extreme events may also **blur predictability outside the wettest period of the season** (as the phase of the onset and withdrawal stages – Moron et al. 2017) ;
- **No clear relationship amongst the bandwidths** (Krishnamurthy and Shukla, 2000, 2007) : any « short » quasi-periodic variations does not necessarily contribute to the predictability of slower variations if it leads to near-zero anomalies for time averages

We propose a complementary approach starting from the **local-scale wet events** -WE- defined from hourly records of rainfall across India (64 stations, 1969-2016) : nor filtering, neither averaging in time and space. The goal is to analyse the contribution of the WE to temporal averages and extremes of rainfall and their statistical and dynamical predictability

Setting the scene of predictability





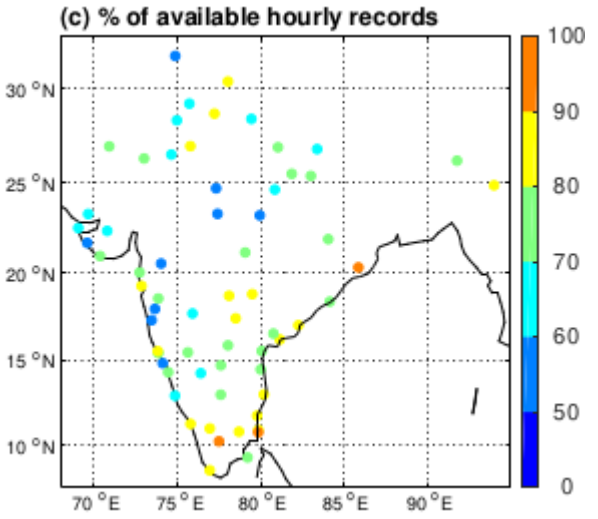


India predictability benefits from a relatively large (vs all tropical land), 20-90 day variance, and the skill of rainfall for week1+2 is relatively large … but suffers from a strong intensity at daily time scale !

(Moron and Robertson, subjudice to IJOC)

Definition of wet events (WEs)

- Hourly rainfall from 64 stations (1969-2016)
- Definition of **372402** WEs from time sequences of hourly rainfall (threshold = 0.1 mm)
- 0 0.1 0.2 5 0 0 0 0.1 0 0 0 0 0 2 20 1 3 0.05 …



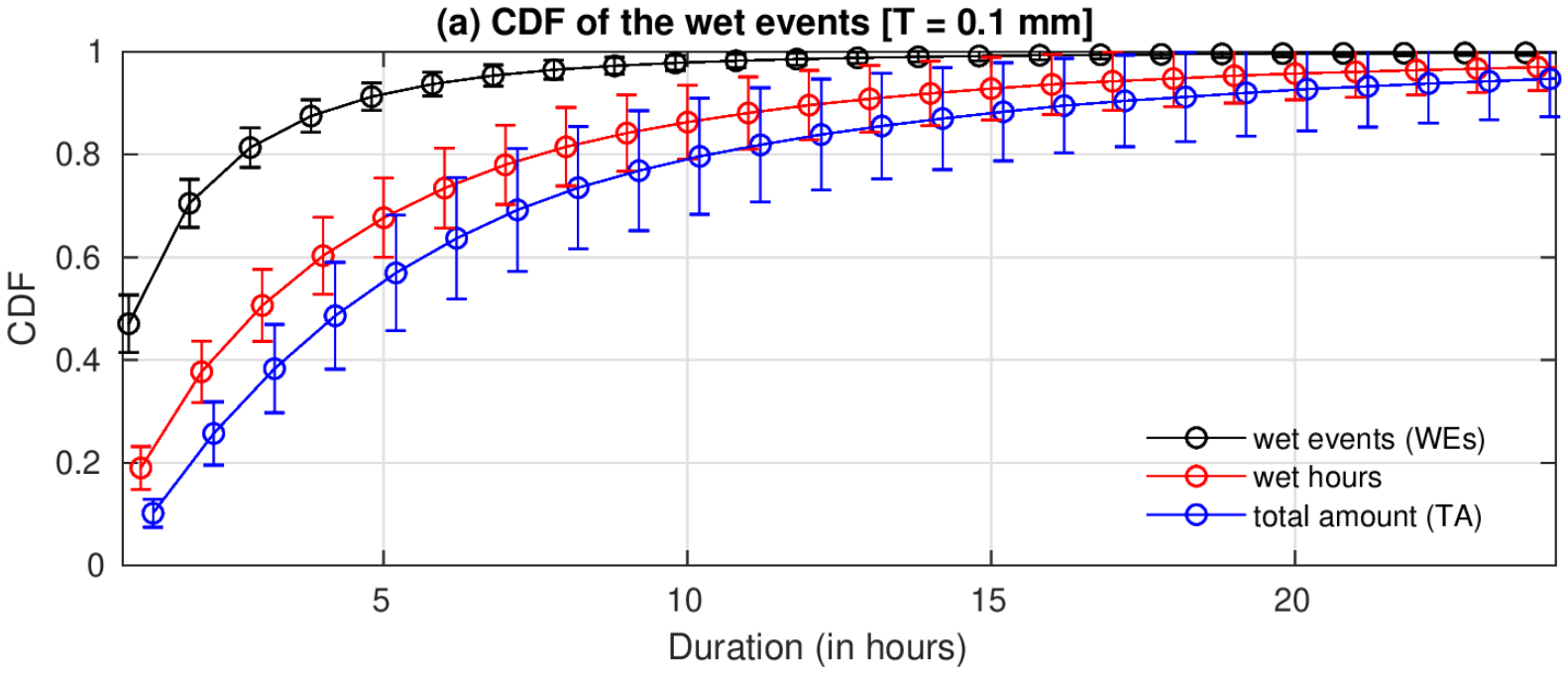
Wet event n°1
- duration = 3h
- total rainfall = 5.3 mm
- mean intensity = 1.77
- max intensity = 5 mm

Wet event n°2
- duration = 1h
- total rainfall = 0.1 mm
- mean intensity = 0.1 mm
- max intensity = 0.1 mm

Wet event n°3
- duration = 4h
- total rainfall = 26 mm
- mean intensity = 6.5 mm
- max intensity = 20 mm

- Phase of the WE is also analyzed

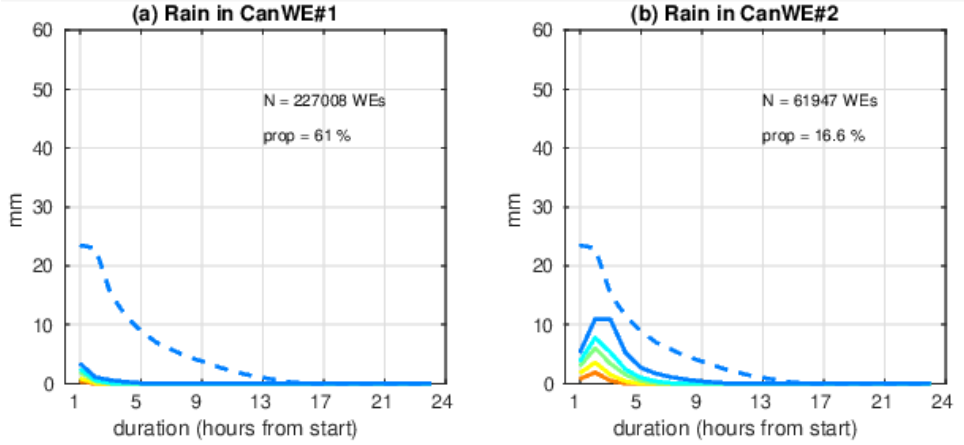
CDF of wet events by duration

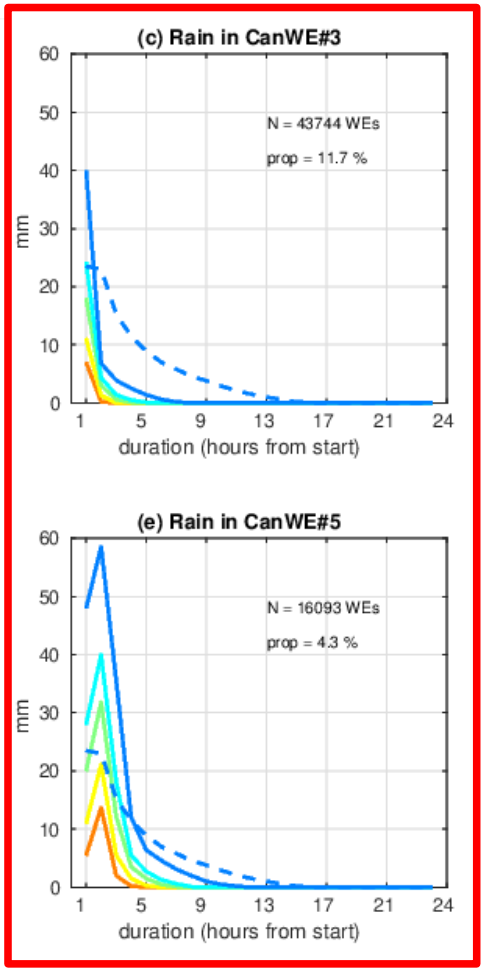


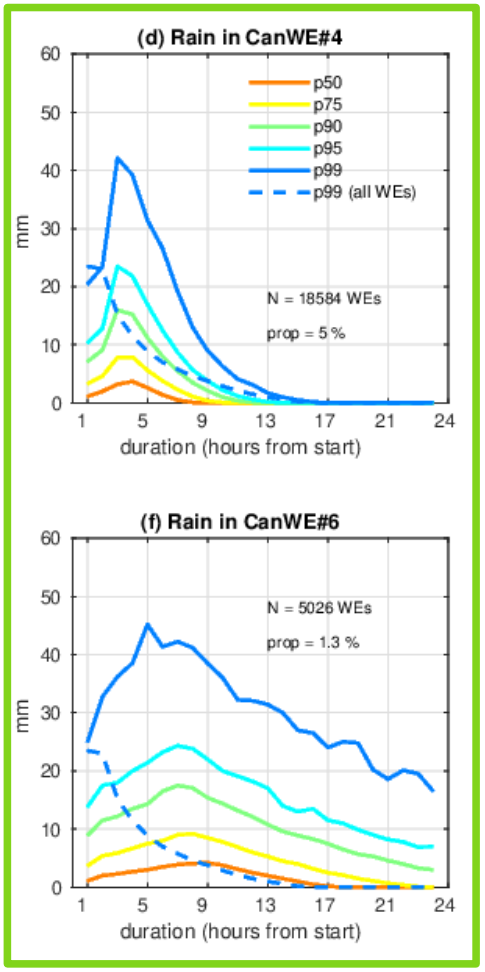
Details in Moron et al. 2021 - Storm types in India: linking rainfall duration, spatial extent and intensity. Phil. Trans. R. Soc. A 379: 20200137. https://doi.org/10.1098/rsta.2020.0137

- 90 % (= average across the 64 stations) of all 372402 WEs last ≤ 5 hours and account for ~70 % of total wet hours ≥ 0.1 mm and ~60 % of total rainfall
- The 372402 WE are clustered using a k-means (using the square-rooted hourly rainfall between 1 and 24 hours from the start of each WE normalized by the hourly average across all Wes) : clusters are thus defined from (1) duration and (2) hourly intensity
- The 6 clusters are called « canonical WEs » or simply **storm types (ST)** in the following

The 6 storm types



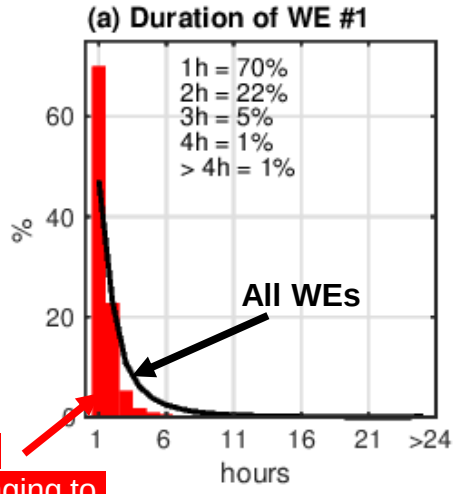


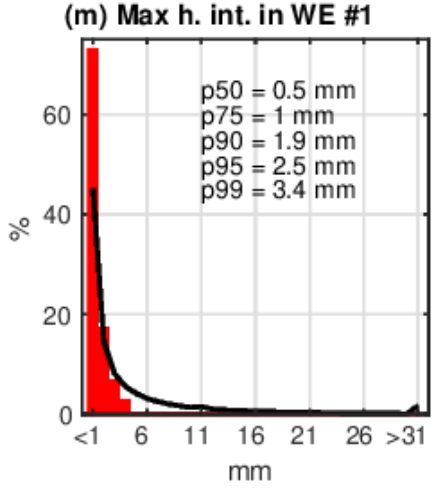


- ST#1 and #2 ; weak and short WEs
- **ST#3 and #5** : possibly intense (esp. ST#5) during the first two hours but short WEs
- **ST#4 and #6** : far longer (esp. ST#6) WEs with larger total at the end, but not necessarily the most intense rainfall at hourly time scale

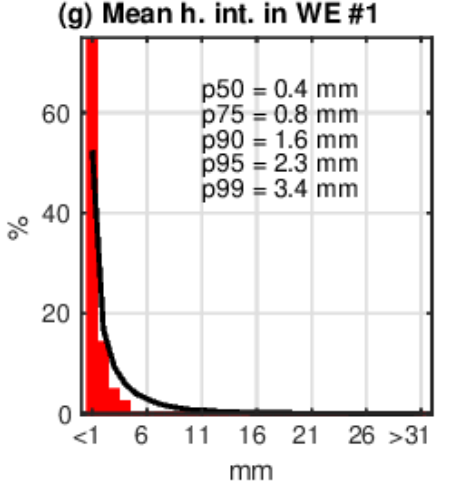
Percentiles 50th, 75th, 90th, 95th and 99th of hourly rainfall for each ST (+ p99 for all hourly rainfall in blue dashed line)

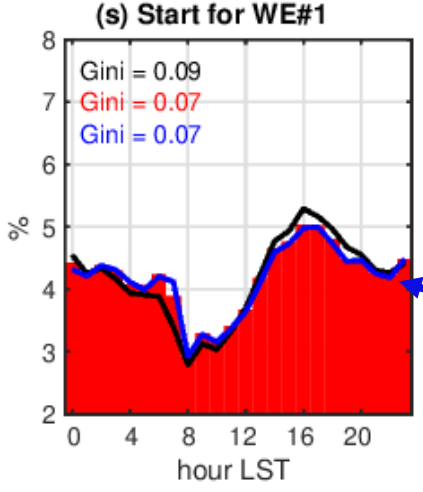
Details of ST#1





WEs belonging to ST#1

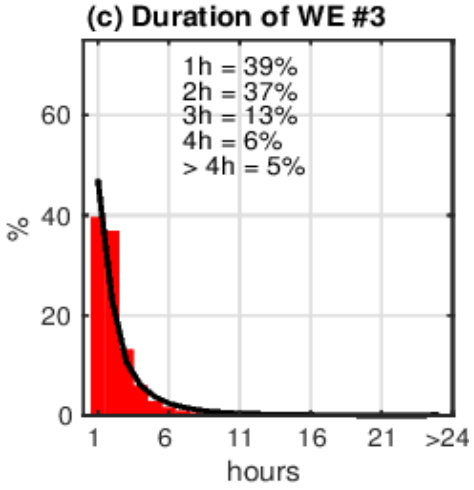


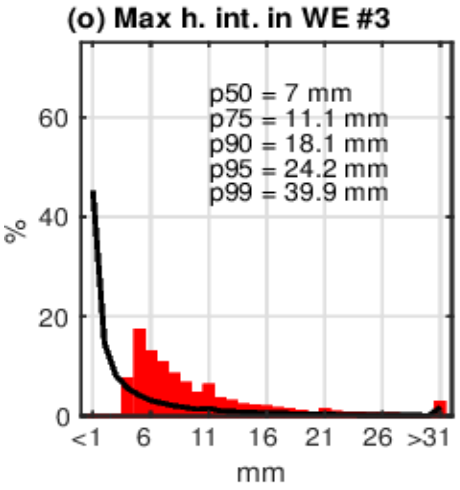


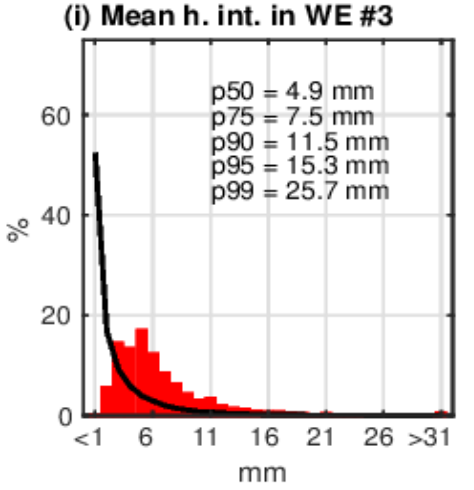
- very frequent (61 % of all WEs)
- shortest (92 % ≤ 2 hours)
- weak rain intensity
- ~10 % of annual rainfall
- no specific phase locking with the diurnal cycle (starting hour is close to the PDF of all WEs with max. in afternoon)
- weak convection ? edges of larger and longer systems ?

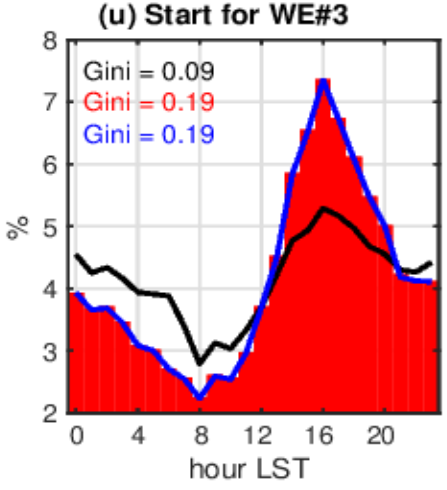
Peak of hourly rainfall for WEs belonging to ST#1

Details of ST#3



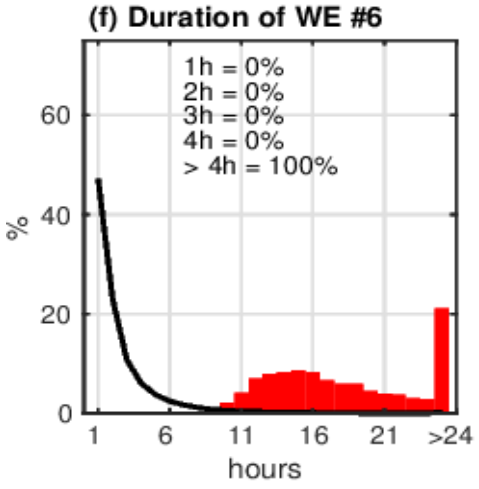


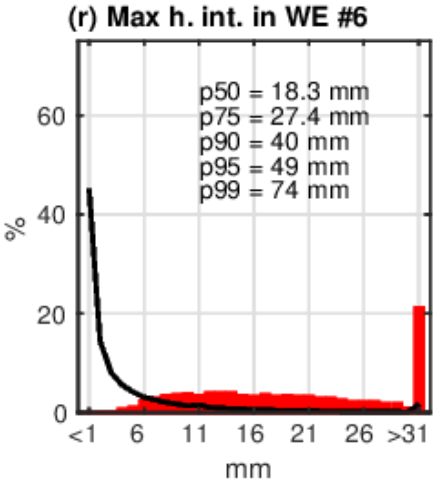


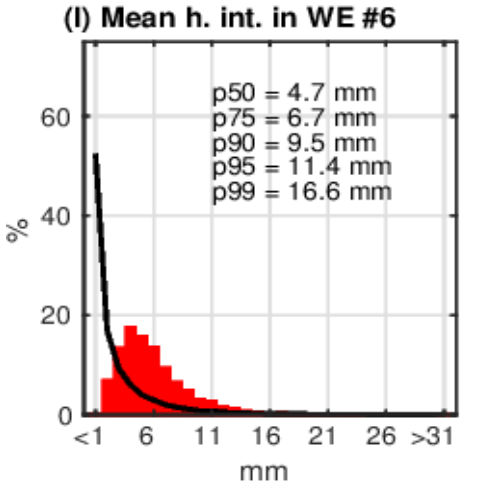


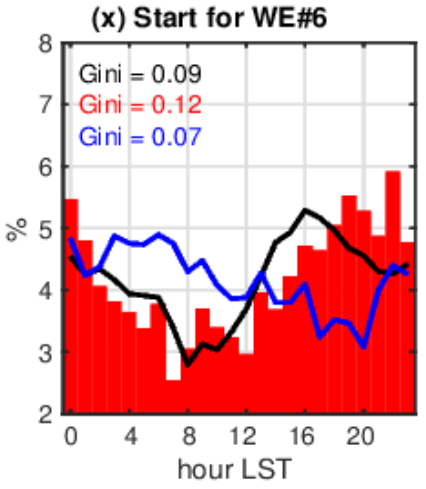
- rather frequent (12 % of all WEs)
- short (76 % ≤ 2 hours)
- very intense in mean
- ~20 % of annual rainfall
- strong phase locking with the diurnal cycle (start usually in mid-late afternoon)
- Isolated or few Cb, but with possible deep convection ?

Details of ST#6

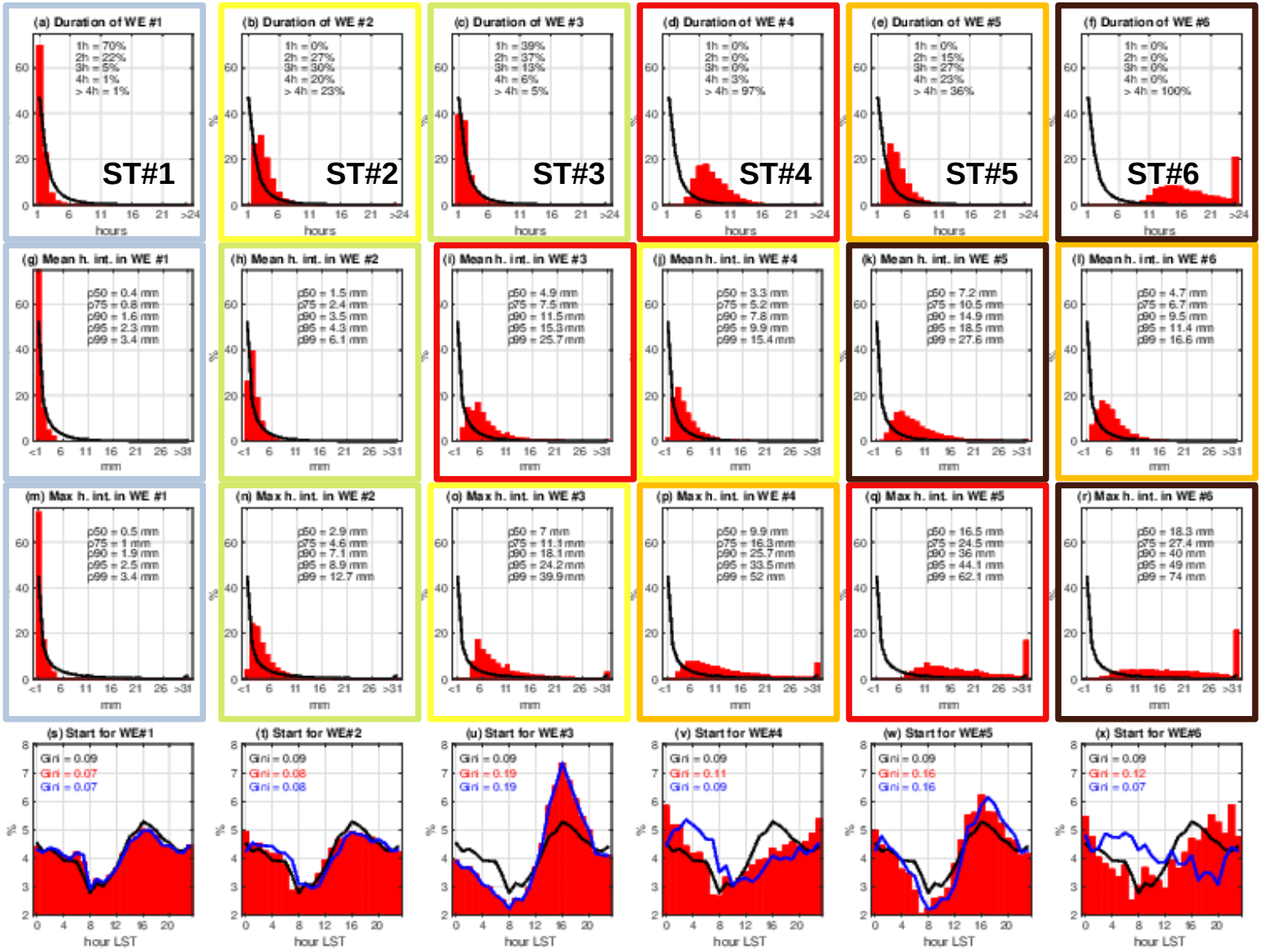








- very rare (1.3 % of all WEs)
- longest (usually ≥ 10 hours and 20 % more than one day)
- strong mean intensity (but weaker than ST#3) with large extreme peaks
- ~20% (average over the 64 stations) of annual rainfall
- starting delayed to nighttime (and maximum rainfall during morning)
- LPS ? Large MCS ?



1 2 3 4 5 6

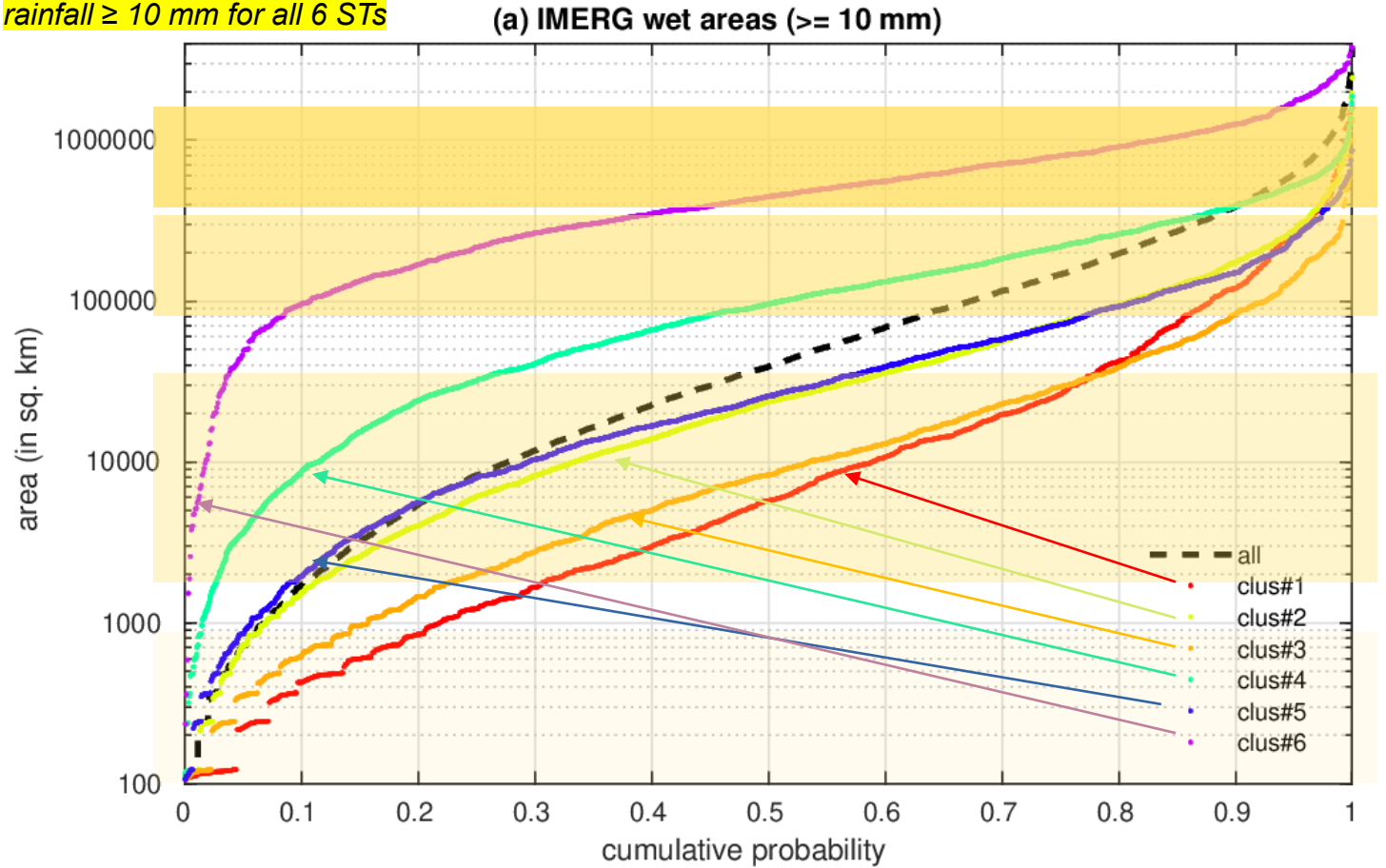
ST#5 ~ ST#3 with longer duration (64 % ≤ 4 hours), very intense rainfall in mean and more phase-locked to diurnal cycle than the whole WEs

ST#4 ~ ST#6 with shorter duration (but 97 % ≥ 4 hours), slightly less intense rainfall

ST#2 = mixing between ST#1 (weak intensity) and ST#4

Spatial scales of the STs

Continuous area of IMERG (0.1° x 0.1°, 30', since June 2000) total rainfall ≥ 10 mm for all 6 STs



~ LPS, cyclone

MCS

« super » cells , meso-scale vortex, etc.

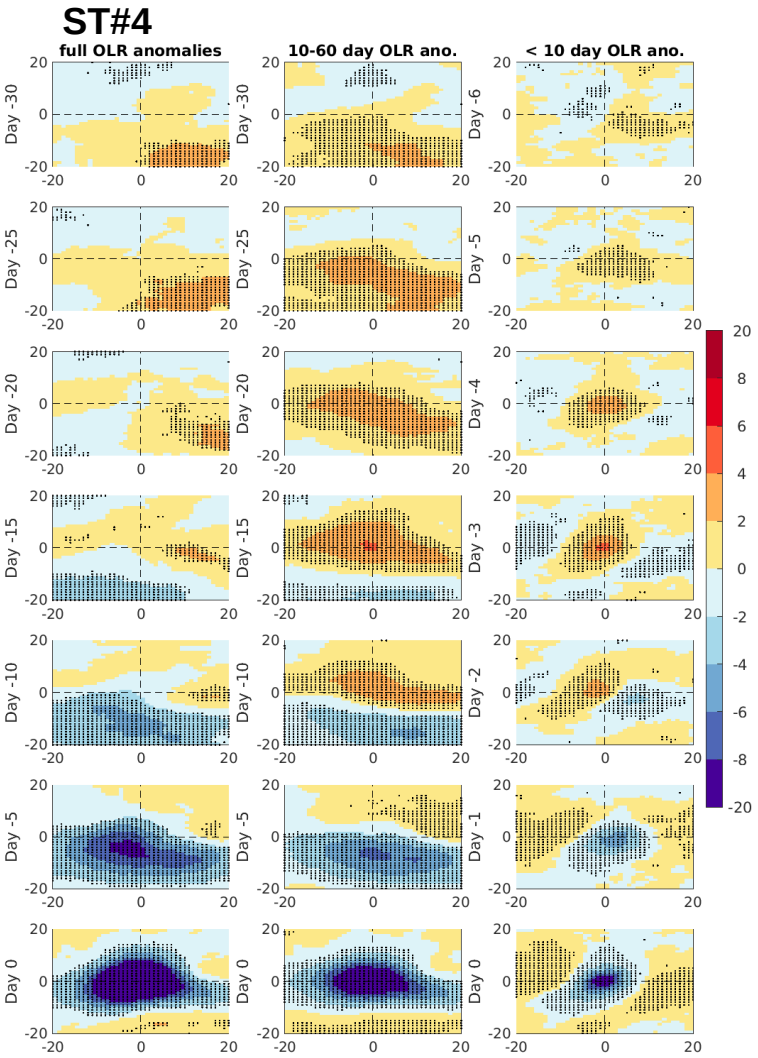
Cb

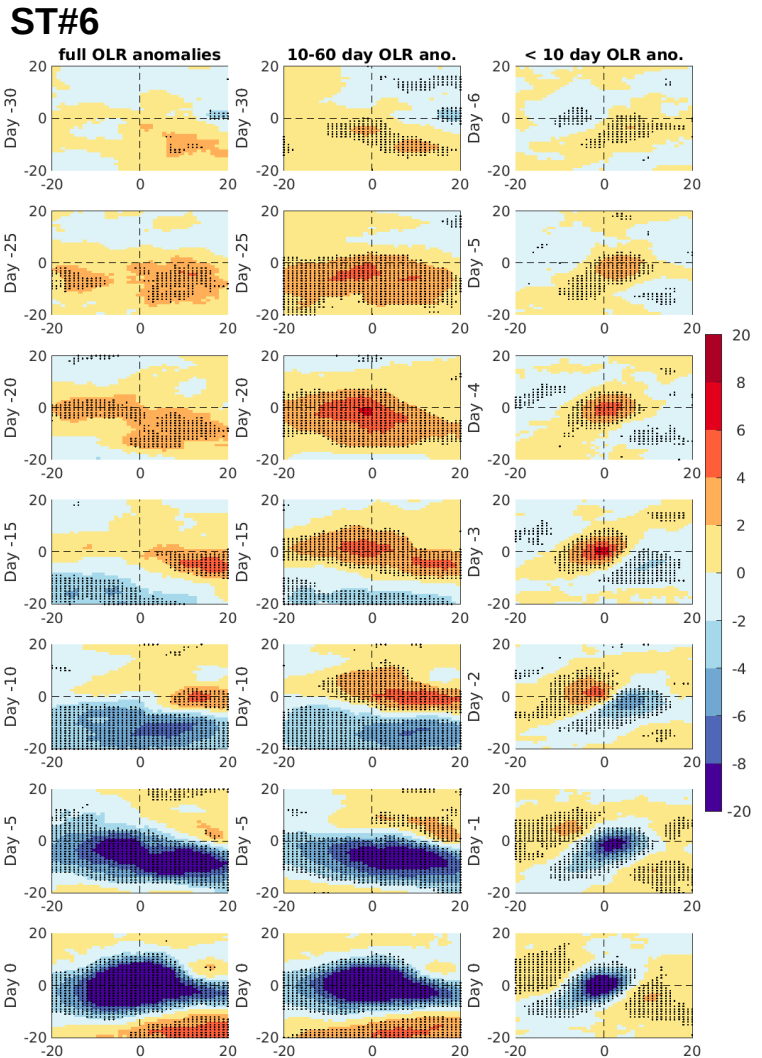
Systematic link between STs and size/duration :

Local ST#4, and especially #6, ~ large wet area

Local ST#5, and especially ST#3, ~ reduced wet area

Space-time scales of the STs (1)



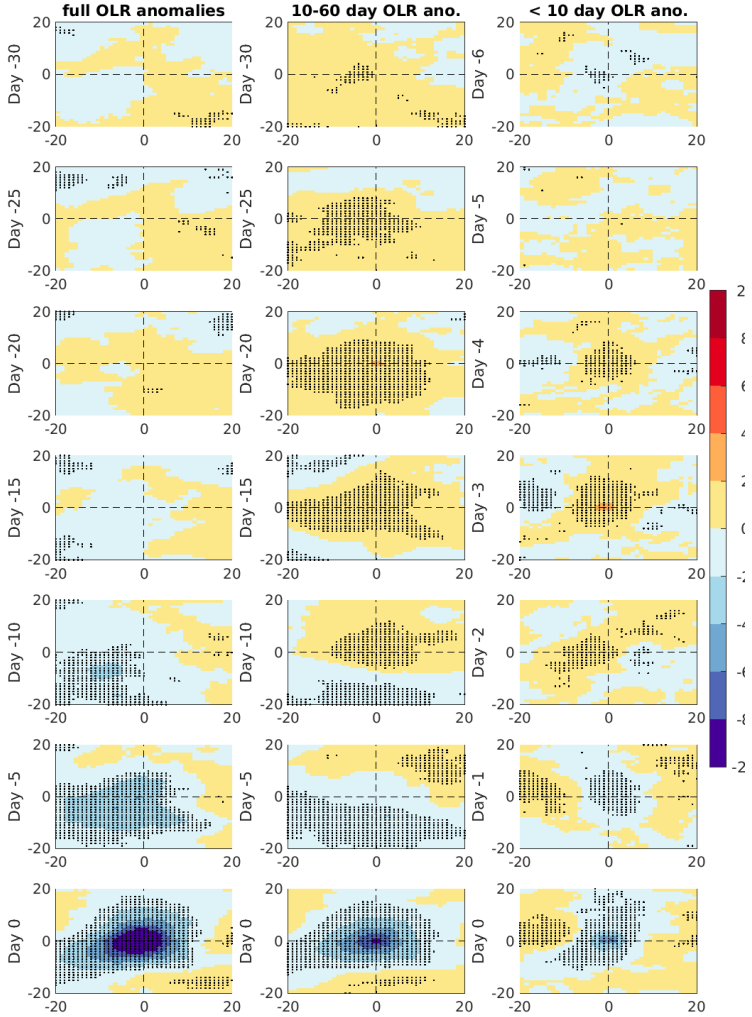


OLR anomalies (daily 1° x 1° from 1979) in W/m² on a 20° x 20° grid targeted to (0,0) which is the location of ST (if daily rain amount ≥ 10 mm) vs the mean annual cycle and filtered anomalies on 10-60 (between day-30 and day0) and < 10 days bandwidths between day-6 and day0). Dots are significance at the two-sided 99 % level

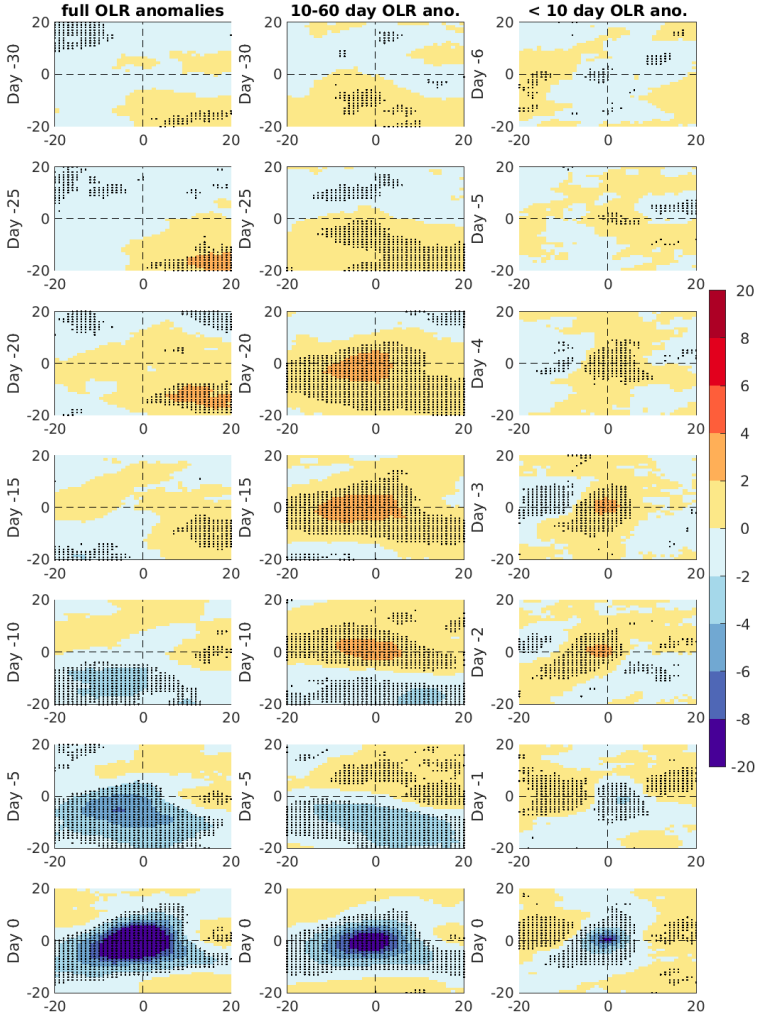
ST#4, and especially ST#6, are both related with regional-scale ISO (northward propagating BSISO) and synoptic signals (mostly LPS travelling ESE-WNW in mean)

Space-time scales of the STs (2)

ST#3



ST#5



OLR anomalies (daily 1° x 1° from 1979) in W/m² on a 20° x 20° grid targeted to (0,0) which is the location of ST (if daily rain amount ≥ 10 mm) vs the mean annual cycle and filtered anomalies on 10-60 (between day-30 and day0) and < 10 days bandwidths between day-6 and day0). Dots are significance at the two-sided 99 % level

Broadly the same signals as for ST#4 and #6 but the precursor signals either in ISO or synoptic bandwidth are weaker, especially for ST#3

Estimation of the S2S predictability of STs (1)

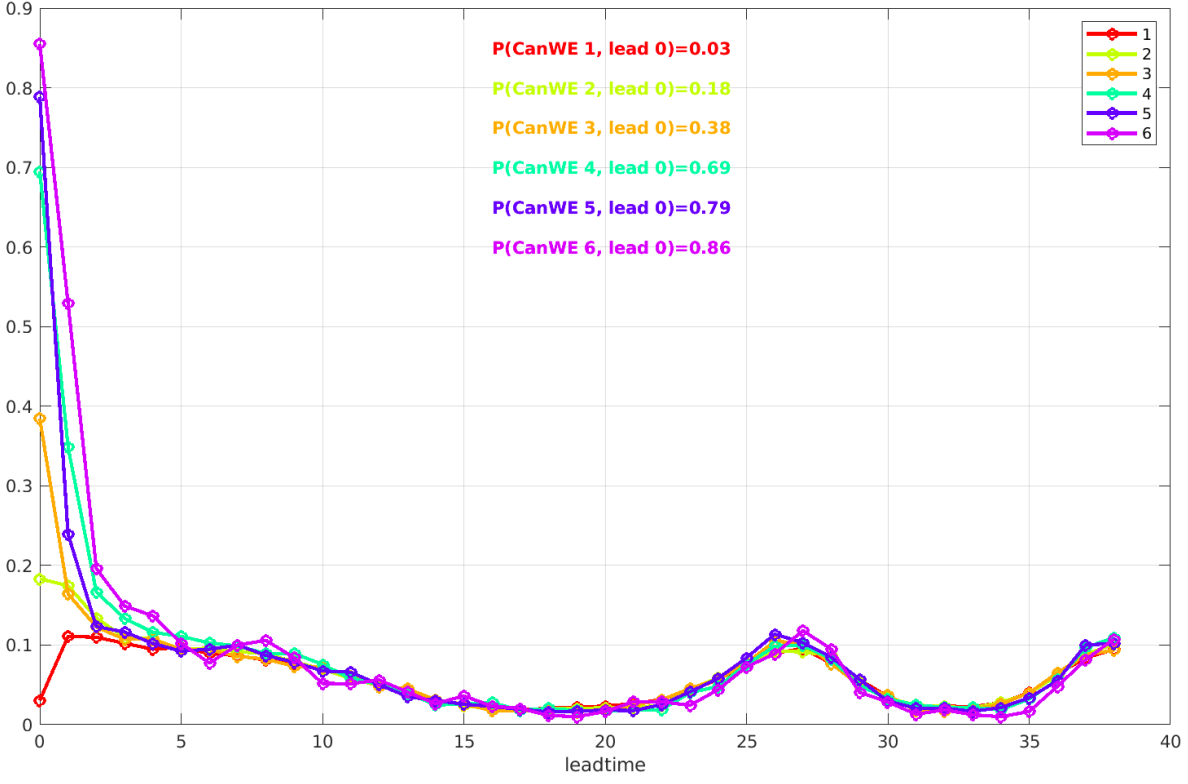
- Analysis of the S2S predictability of **« extreme » STs** (i.e. receiving at least a total of 10 mm of rainfall) using an ensemble of 11 ECMWF runs with 105 starting dates per year (1998-2017) and a leadtime of 46 days (only the leadtime till 38 days are analyzed here)
- infradaily wet events are « upscaled » to daily rainfall
  - If two WEs co-exist during a given day, the wettest one is retained and the other one is not analyzed further
  - If a WE lasts on two (or more) consecutive days, these days are not merged and considered as individual daily STs
  - The daily rainfall related to the six STs are the targets for the S2S prediction
  - Prediction is evaluated with **probability of exceedance (PoE) of the 95th percentile (P95) of daily rainfall at each station.**
  - **P95 are computed separately on observations and each ECMWF run and leadtime to filter systematic potential biases and spurious drifts**

Estimation of the S2S predictability of STs (2)

- Daily observed and ECMWF (each run of the 11-member ensemble) rainfall are converted into a binary score = 1 ≥ local 95th percentile (P95) and = 0 < local 95th percentile. P95 is computed separately for each leadtime in ECMWF runs
- Observed P95 varies between 0.4 and 89.4 mm (mean = 19.3 and sd = 15.7 mm) across the 64 stations
- ECMWF P95 (average over the leadtime) (mean = 14.9 mm and sd = 10 mm) with a pattern correlation of 0.65 with observations
- The skill score is the PoE ≥ local P95
- ECMWF Skill score is compared to two benchmark PoE
  - Persistence : it is simply the PoE of daily rainfall ≥ P95 1 to 38 days before the occurrence of daily STs
  - Random : PoE of 100 random reshuffling of observed ST occurrence through the 20 available years only : the seasonal frequency and the geographical location of ST are kept in the reshuffled sequences, so this approach may be weakly « conservative » as ST may occur on the same day

PoE of observed persistance

Probability of exceedance - PoE- of local P95 vs leadtime (averaged over all WEs belonging to a given ST)



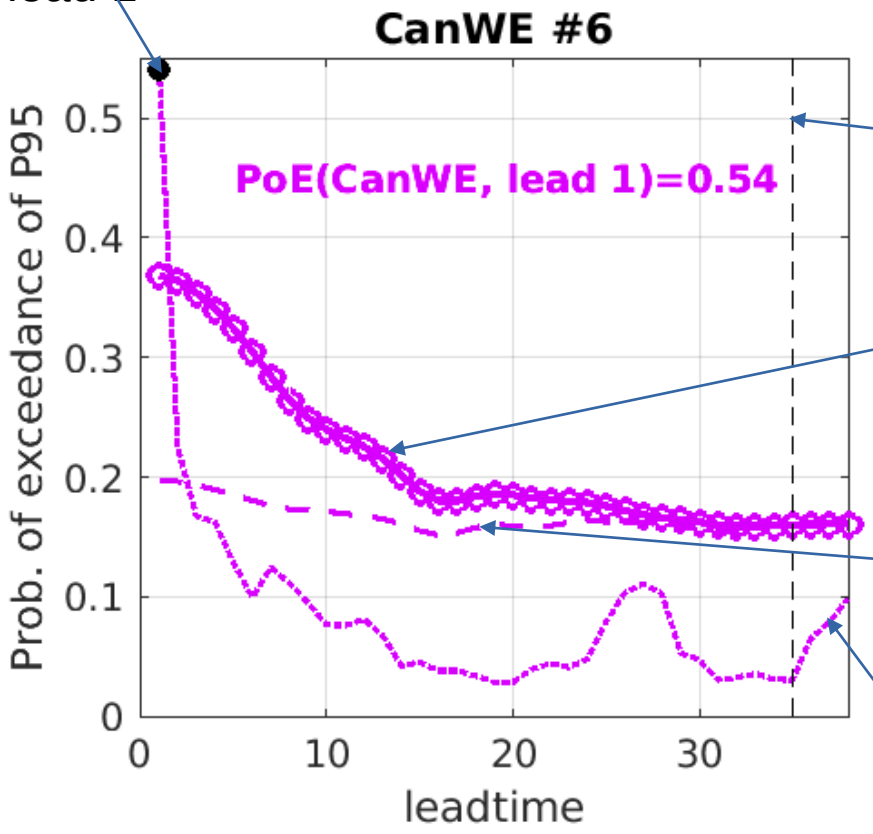
Fast and consistent decrease from day0 till ~0.1 at day-2 to -5

ST#6 and #4 have slightly larger values at day-1 and -2 : simply reflect possible duration across 2 (or even 3 days for ST#6) and also reflect weakly their seasonal dependence (larger occurrence around the core of the rainy season)

Weak increase of PoE around 27 and 38 days may reflect weak quasi-periodic variations in rainfall ?

Skill of S2S prediction (1)

PoE from persistance at lead 1



Mean probability of exceedance of P95 for S2S forecas, persistence and random (averaged over all WEs belonging to ST#6)

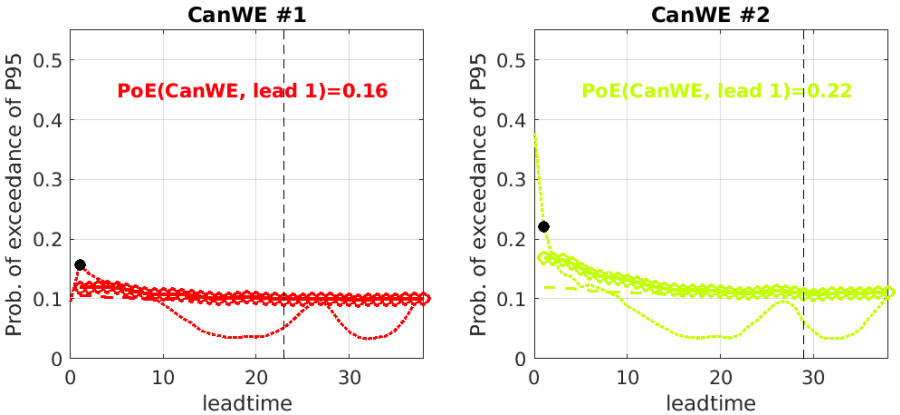
Leadtime when S2S PoE > 99th of random forecast

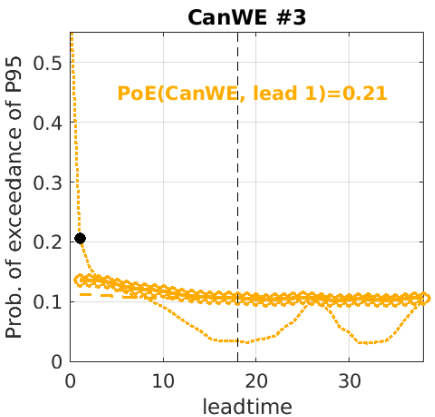
PoE from S2S forecast (low-pass filtered with a 5-order Butterworth filter to smooth the noise due to discontinuous initial dates every 3-4 days)

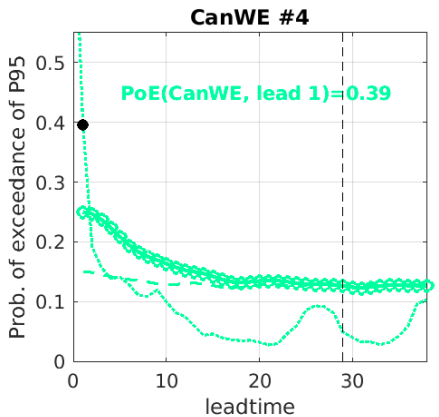
PoE from random forecast (99%)

PoE from persistence

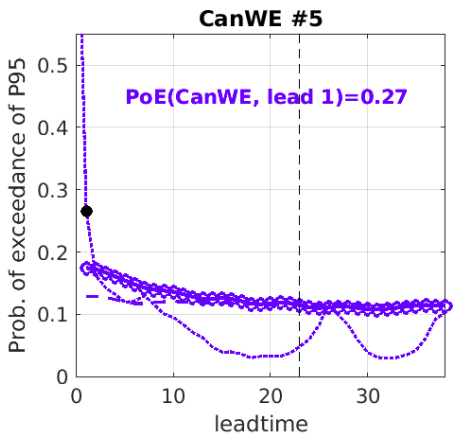
Skill of S2S prediction (2)

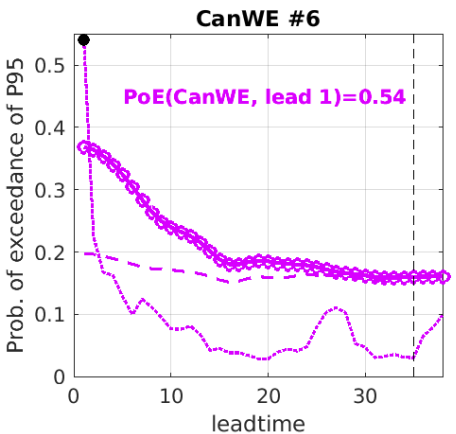






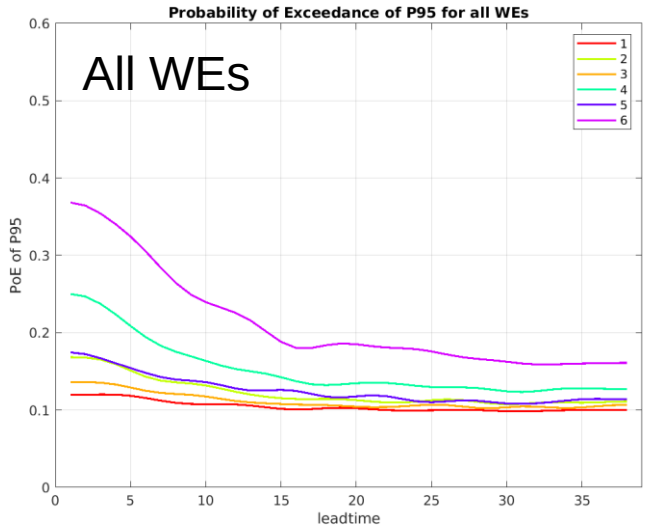
- S2S fcst is larger for ST#4 and #6 and very low for ST#3
- random fcst is larger for ST#6 (and slightly for ST#4) vs other STs due to their larger climatological occurrence during the wettest period of the year (thus related with increased frequency of P95)
- S2S fcst is larger than random fcst till 17 -22 days for ST#3 and 5 vs 30-35 days (ST#4 and #6)





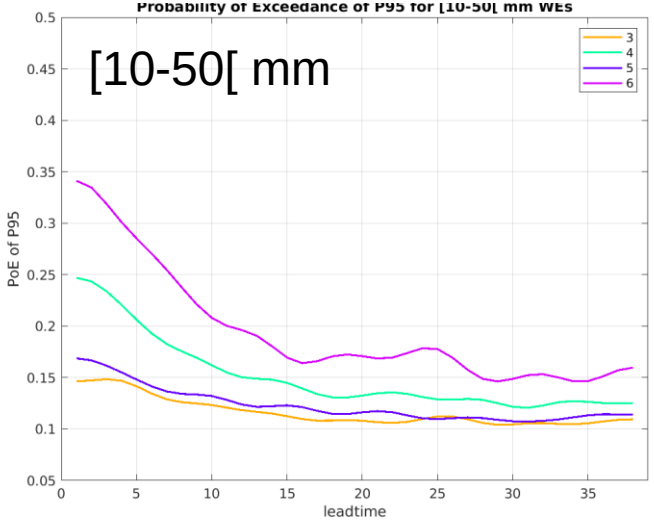
Mean probability of exceedance of P95 for S2S forecast vs random & persistence forecasts (averaged over all WEs belonging to ST#1 to ST#6)

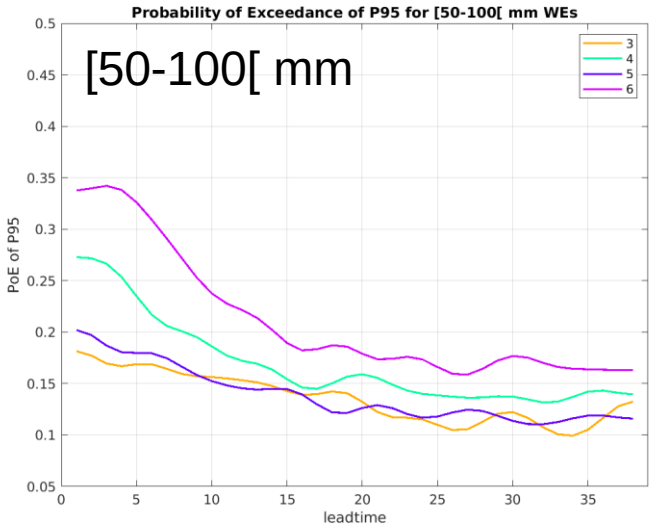
Skill of S2S prediction (3)

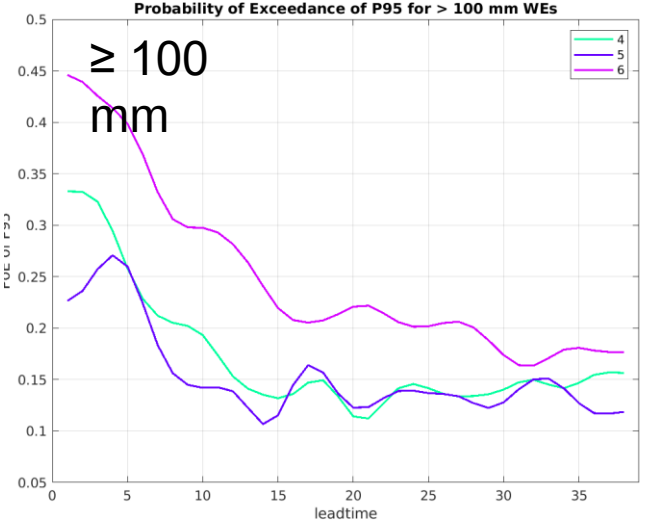


Mean probability of exceedance of P95 for S2S forecast (averaged over all WEs belonging to ST#3 to ST#6 and then discriminated according to the total rainfall at the rain gauge)

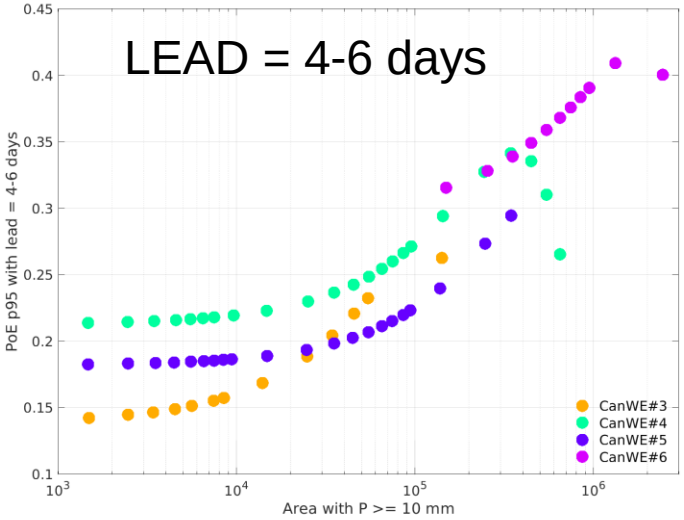
The better forecasts of ST#6 and then ST#4 are not only an artefact of the larger amount of rainfall during these events : here PoE of P95 for daily rainfall between 10 and 50 mm, 50-100 and above 100 mm gets the **same relative ranking of performance**

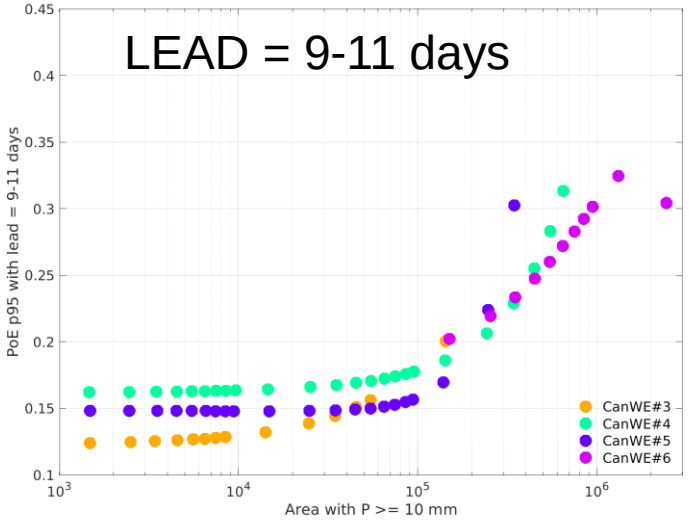






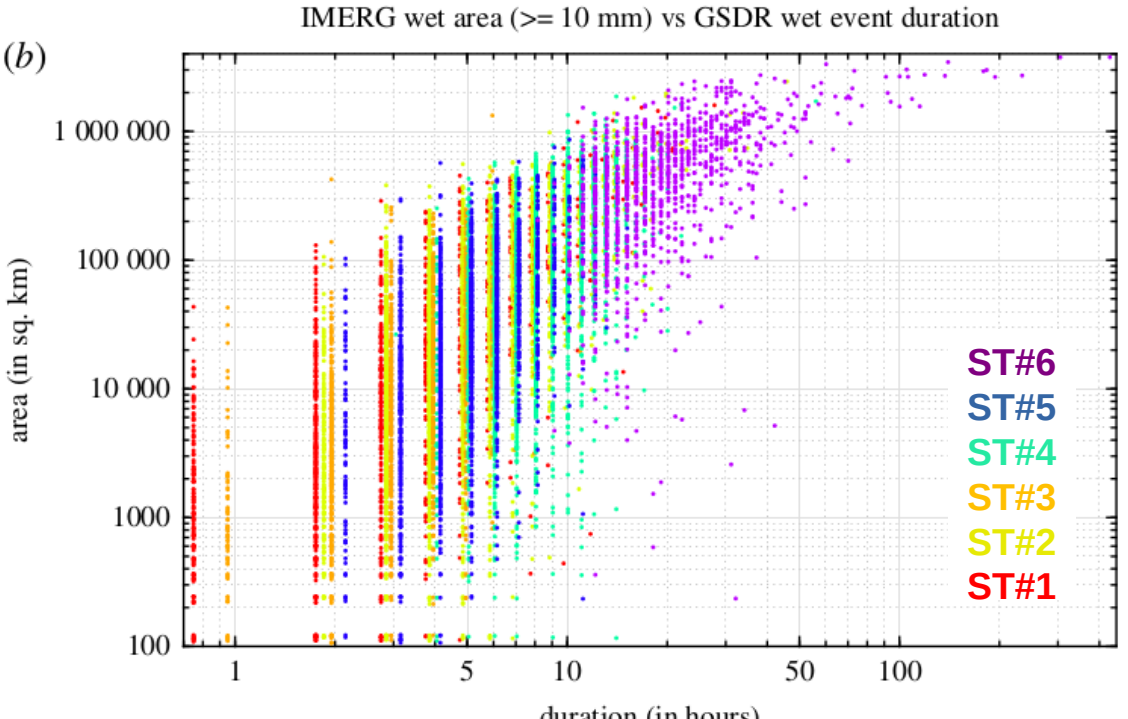
Predictability vs scale/duration of WEs





2-order polynomial fit of the PoE of p95 vs IMERG area ≥ 10 mm for 4-6 days leadtime (upper panel) and 9-11 days leadtime (lower panel) for the ST#3 to #6 receiving at least 10 mm

Continuous area of IMERG (0.1° x 0.1°, 30', since June 2000) total rainfall ≥ 10 mm vs duration of Wes at the station for all 6 STs



Conclusions

- Local infra-daily ST offers a possible consideration of wet events through their **intensity and duration**. Due to the ergodic nature of climate, they also offer a consideration of the **spatial extent of the wet events**. These intrinsic characteristics are partly blurred in time-averaged or filtered quantities
- 2 STs (ST#3 and ST#5) are associated with **possibly very intense rainfall** but **short** duration and **small area** covered by rainfall ≥ 10 mm
- 2 STs (ST#4 and mostly ST#6) are associated with **slightly weaker mean intensity** but **higher total amount**, **longer** duration and **larger area** covered by rainfall ≥ 10 mm. These STs are also more locked to the main intraseasonal and synoptic modes of variation than ST#3 and #5
- ST#1 is related to very weak amounts while ST#2 seems to be mostly an attenuated version of ST#4-#6 family
- ST#4 and mostly ST#6 (and also ST#2) are **better predicted** by ECMWF S2S ensemble than ST#3 and ST#5. It is also fully consistent with the larger related spatially-coherent intraseasonal and synoptic-scale precursors

Possible future works

- As ST#3 and ST#5 contributes both to ~ 40 % of total yearly amount in mean, it may be interesting to look at **their possible consequences on the potential and real-time predictability of seasonal amounts** : we may raise the hypothesis that their contribution may establish an upper limit of the predictability of seasonal amount
- In the same context, **does a year with a lot of ST#3 and #5 vs ST#4 and #6 being less well predicted or not** ?
- What is the relationship with **risky impacts as flash floods** ? The yearly hourly maximum (by station) usually occurs during ST#5 (43%) far behind ST#3 (21%) which are the most challenging to predict at S2S time scales …
- Climate change ? **How the global warming may impact the occurrence of STs** ? It is possible that warming promotes relatively more ST#3 or ST#5 …

Few References

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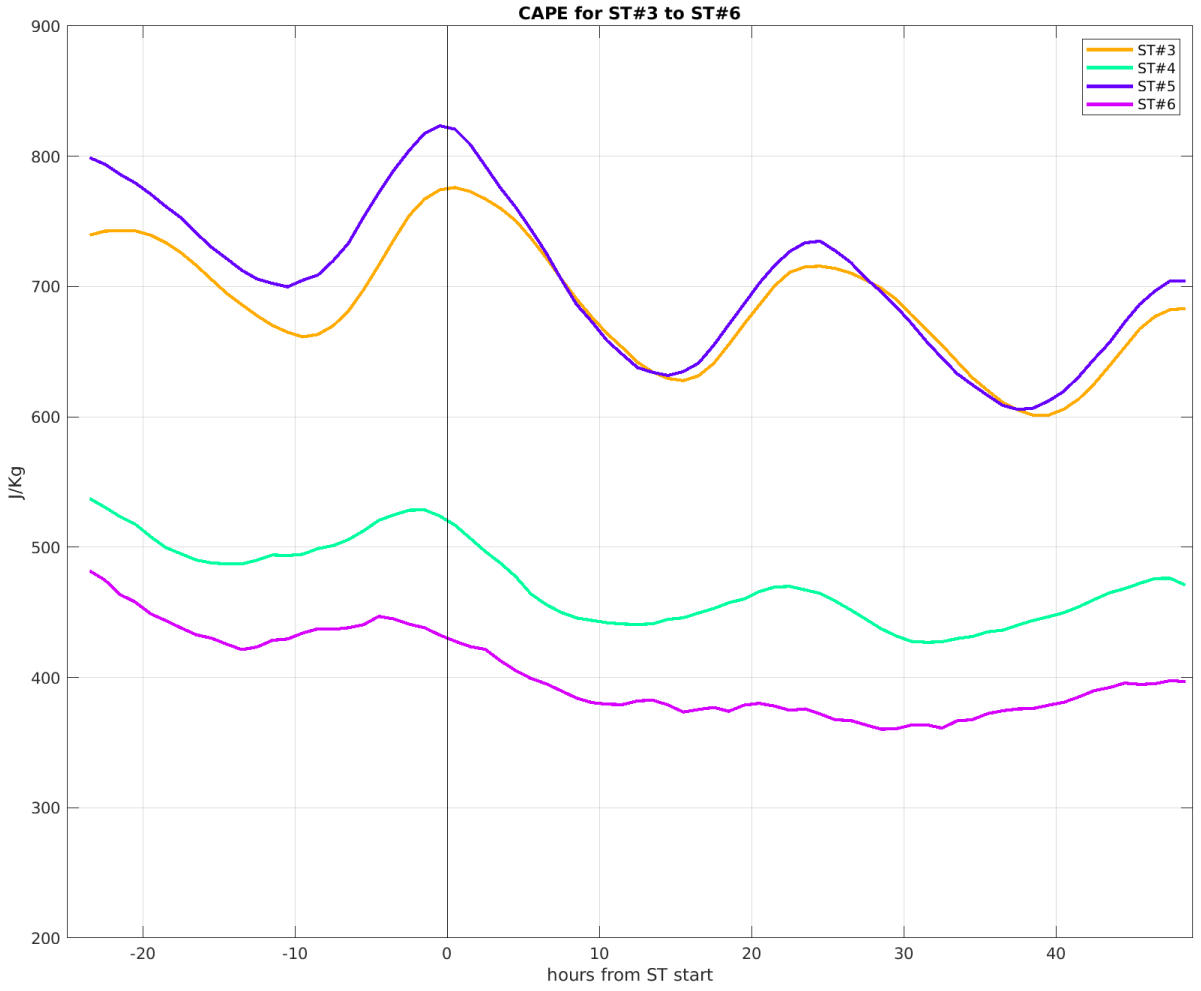
Additionnal slide (1)

Statistics of the « daily » ST on 1998-2016 (when ECMWF prediction is available)

	Total number	Mean daily rainfall in mm	Nb ≥ 5mm	Nb ≥ 10mm
CanWE#1	25882	2.2	1799	751
CanWE#2	12016	8.8	7546	3687
CanWE#3	9750	15.4	8661	5736
CanWE#4	5376	36	5010	4716
CanWE#5	4681	36.7	4440	4382
CanWE#6	2260	82.8	2179	2129

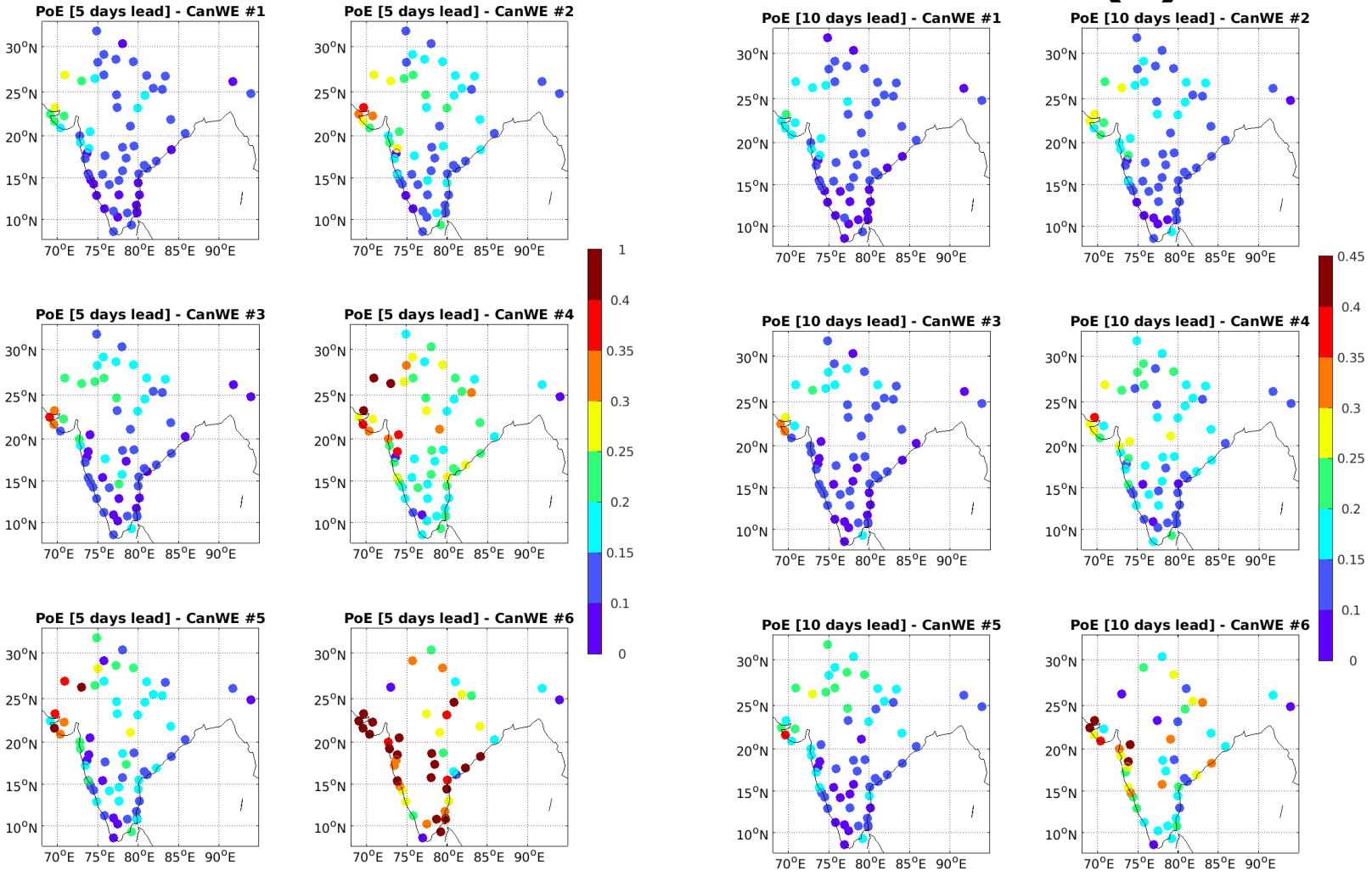
Additionnal slide (2)



Average hourly Convective Available Potential Energy from ERA5 related to ST#3-ST#6

- the instability is larger during ST#3 and #5 vs #4 and #6
- consistently, the phase locking to diurnal cycle is also stronger for the former vs the latter STs

Additionnal slide (3)



Station-scale PoE of P95 at leadtime=5 and 10 days for ST#1 to #6

Usually larger skill for NW India