# Forecasting springtime Sahelian heat waves at seasonal and sub-seasonal time scales

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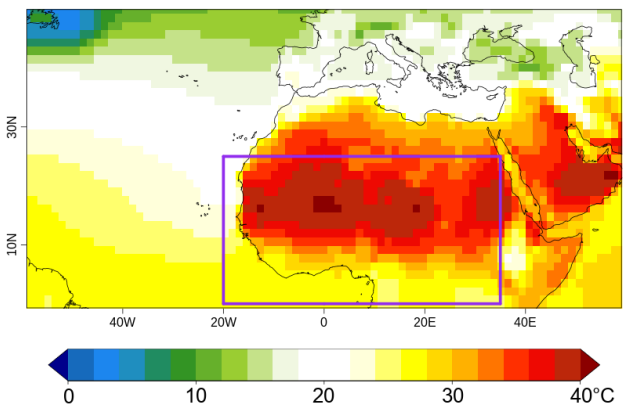
# Framework

## French ANR project ACASIS (2014-2018)

- Sahelian heat waves and impacts on health ; coordinator : Serge Janicot
- Collaborative project involving several institutes in France, Burkina Faso and Senegal
- Encompasses the development of a prototype heat wave alert system at NWP and medium-range time scales

## Context

- Focus on Tmax or Tmin heat waves during March to June
- Previous studies show positive trends
  - in temperature over the past decades (Fontaine et al. 2013, Moron et al. 2016)
  - as well as in HW indices (Barbier et al. 2018)
  - and future climate projections suggest increased vulnerability of the region (Russo et al. 2014, Déqué et al. 2017)




ERA-Interim mean Tmax (MAMJ 1993-2014) and region of study

# Heat wave indices : Tmin and Tmax

## Multiple definitions for heat wave indices (see e.g. Perkins, 2015)

- Some common indices (e.g. tropical nights) seem irrelevant for the area of study
- We use daily Tmin (resp. Tmax) climatologies (5-day smoothing) for MAMJ over the 1993-2014 hindcast period
- HW occurs if Tmin (resp. Tmax) exceeds $90^{\text{th}}$ percentile for $>$ 3 days
- **HW Duration Index (HWDI)** : number of days in heat wave conditions per period
- HW Per Period (HWPP) : number of heat waves occurring per period

## References for model evaluation

- Reference is ERA-Interim ; full coverage of re-forecast period and spatial domain
- Similar results are found for Berkeley Earth Surface Temperature (BEST) data over 1993-2013
- Model HW occurrences based on model daily climatology to account for model biases
- These corrections notwithstanding, model HWDI and HWPP are biased
- Extremes/indices forecast skill is related to that of the variable (Bhend et al. 2017, Pepler et al. 2015)

# Heat wave indices : Apparent temperature

## Apparent temperature

- Takes into account relative humidity (computed with 2m dewpoint temperature and temperature ; Lee and Brenner 2015)
- Indicator of heat stress for humans (Fischer and Schär, 2010)
- Complementary to quantile threshold exceedances
- HW indices defined as for Tmin/Tmax but for absolute thresholds

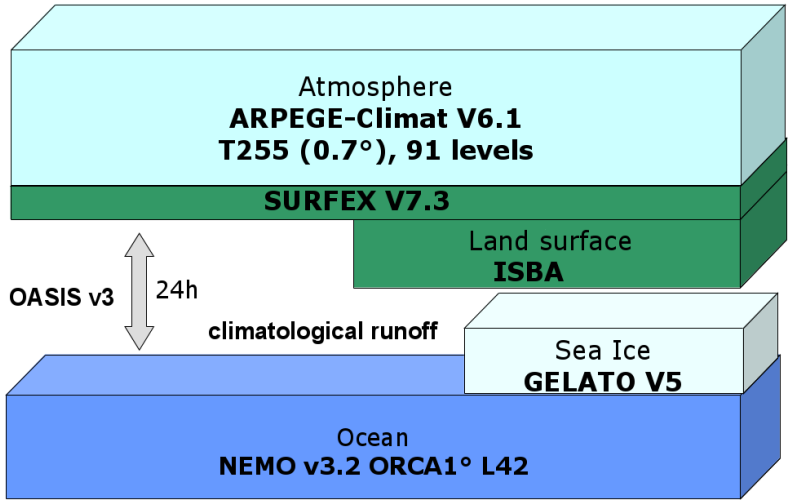
## Limitations

- Caveat : only daily data for dewpoint temperature is available in S2S forecast data
- Computation with Tmax would lead to over-estimation of apparent temperature values
- Compromise : use of daily mean fields and absolute threshold of 35°C
- Two indices : AT35 HWDI and HWPP

# Météo-France seasonal forecasting system 5

## Météo-France system 5

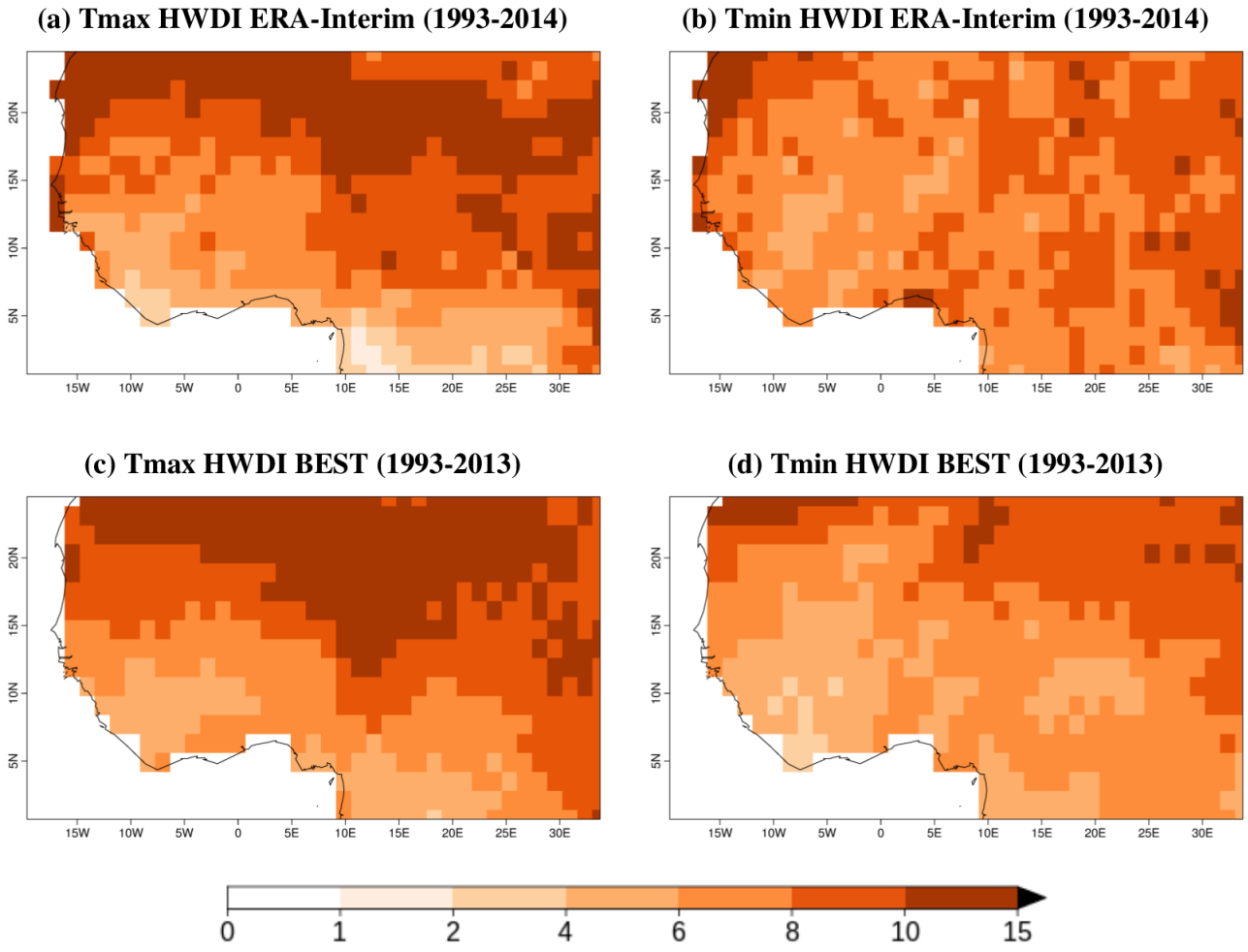
- Based on the CNRM-CM GCM
- System used in several multi-model initiatives :
  - EUROSIP
  - Copernicus C3S
  - S2S (see Ardilouze et al. 2017)
- Upgrade in ARPEGE-Climate atmospheric component




System 5 based on CNRM-CM (Voldoire et al. 2013)

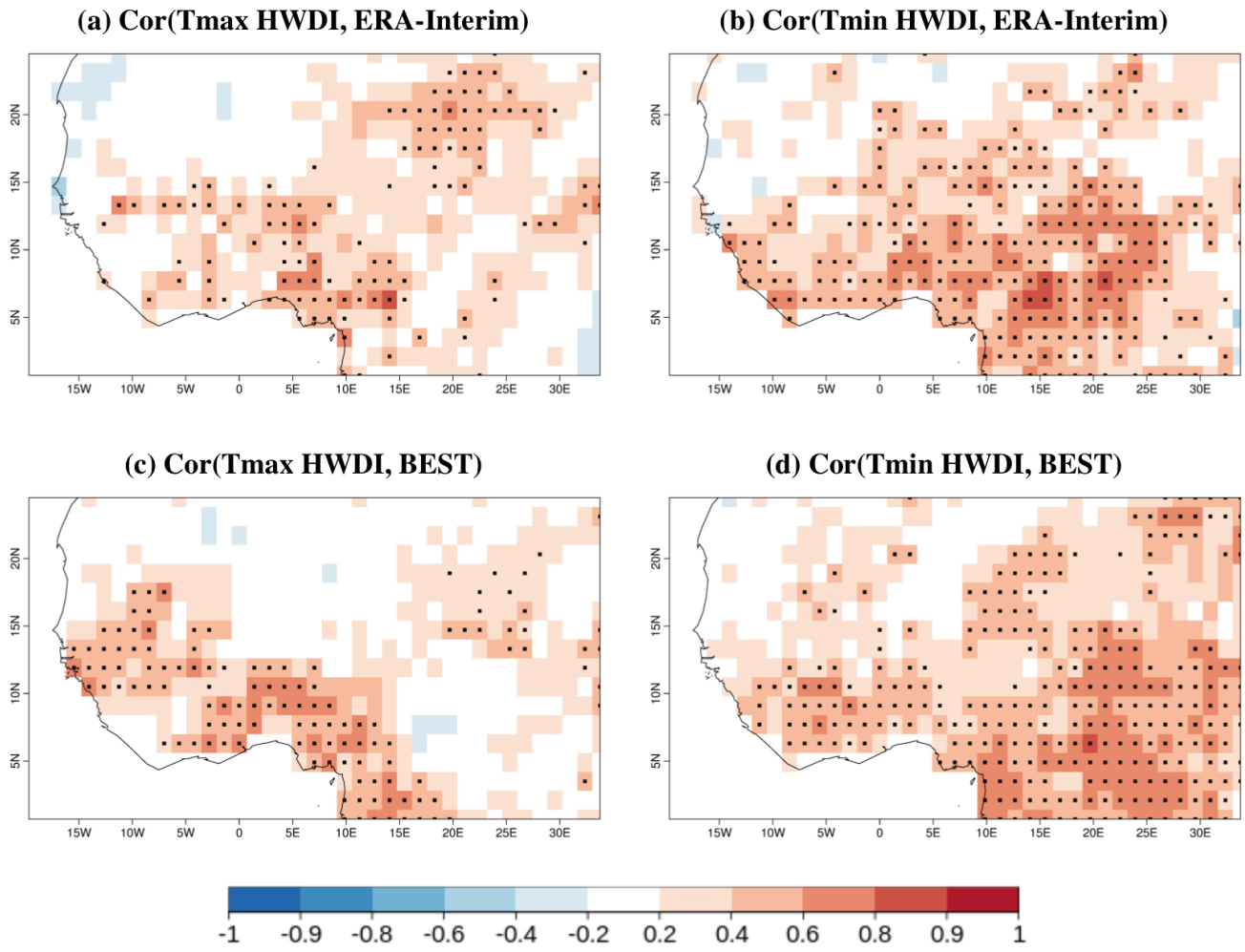
| | | Re-forecasts (1993-2014) | Real time forecasts |
|---|---|---|---|
| **Common features** | Ensemble size | 15 | 51 |
| | Initial conditions | Atmosphere/land : ERA-Interim<br>Ocean/sea ice : Mercator Ocean PSY2G2V3 | Atmosphere/land : ECMWF analysis<br>Mercator Ocean upscaled op. analysis |
| **Seasonal** | Frequency and forecast length | 1st of each month | Two Wednesdays |
| | Ensemble generation | stochastic dynamics | stochastic dynamics + 1 week lag |
| **S2S** | Frequency and forecast length | 1st and 15th of each month | Each Thursday |
| | Ensemble generation | stochastic dynamics | stochastic dynamics |

# Reference data uncertainty



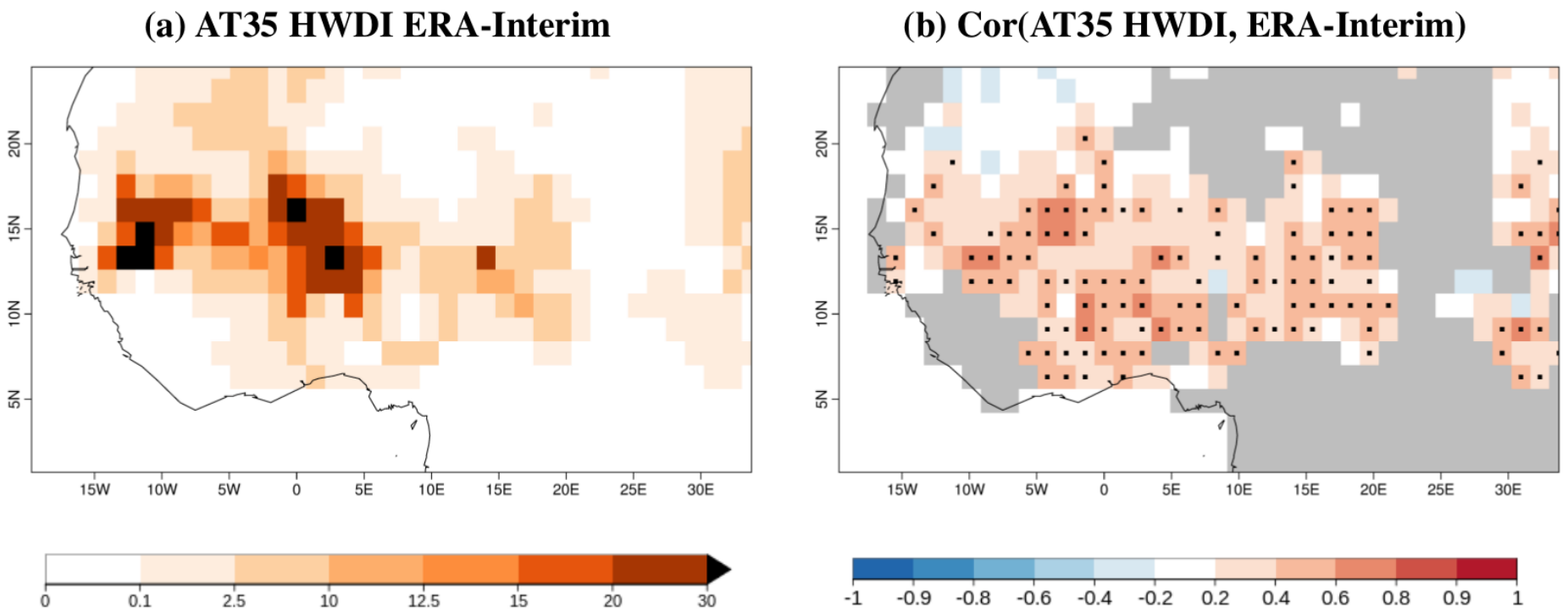

Climatologies of MAMJ Tmax and Tmin HWDI computed with ERA-Interim data for 1993-2014, and BEST for 1993-2013 (due to data availability).

# Spearman correlation of HWDI




Spearman rank correlation of MAMJ System 5 reforecasts for Tmax and Tmin HWDI with respect to indices derived from ERA-Interim (a-b) and BEST (c-d). Dots indicate correlation values significant at a 95% level as estimated by a *t*-distribution accounting for dependence between consecutive forecasts (Zwiers and von Storch, 1995).

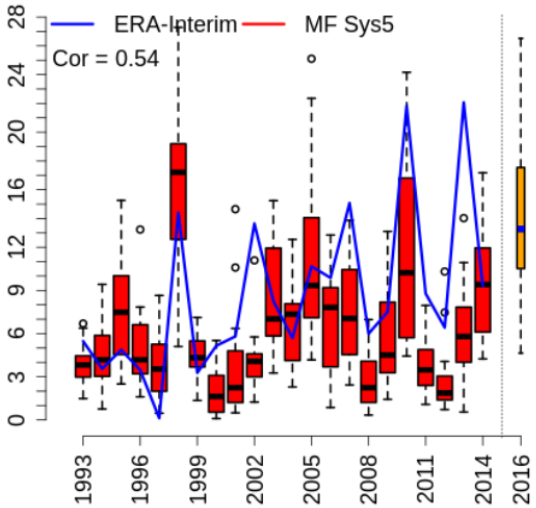
# Apparent temperature



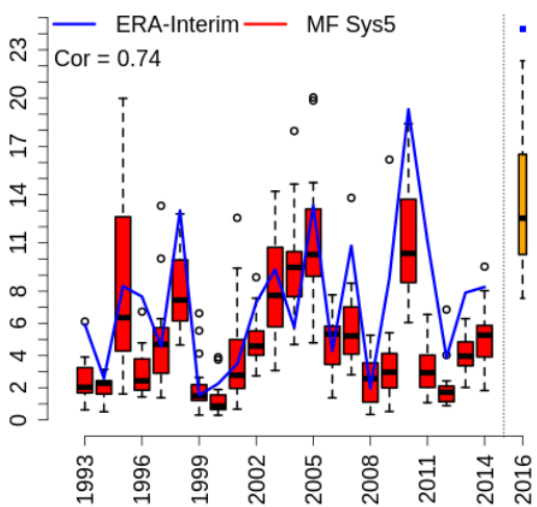

Climatology of MAMJ AT35 HWDI computed with ERA-Interim data for 1993-2014, and Spearman rank correlation of System 5 reforecast MAMJ AT35 HWDI with ERA-Interim over the reference period.

# Skill for regional averages

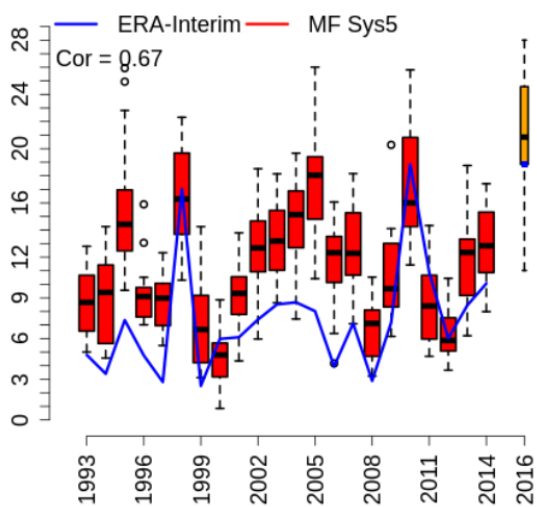
(a) Tmax HWDI




(b) Tmin HWDI

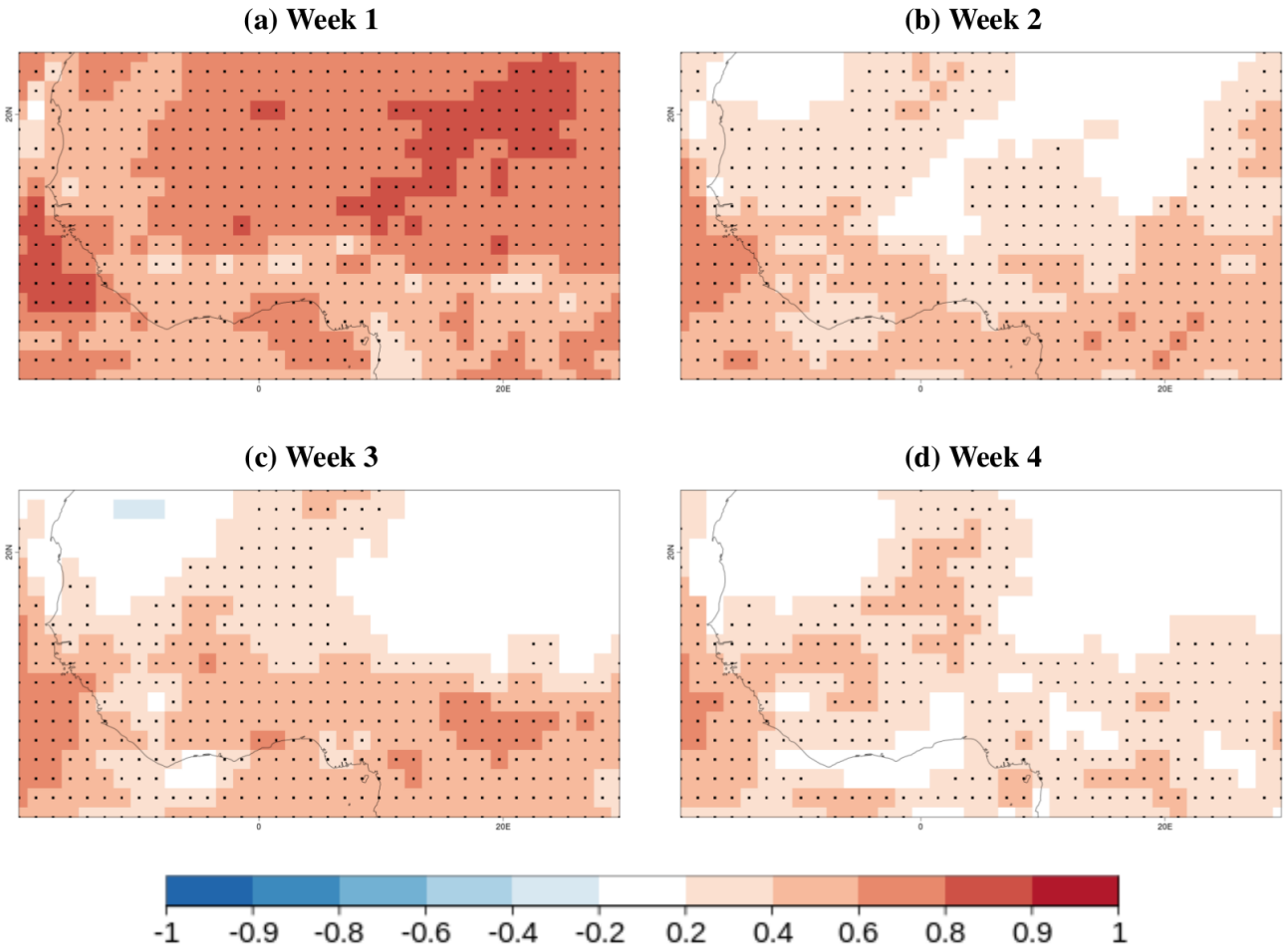



(c) AT35 HWDI




Box-and-whisker plots of the ensemble reforecasts of Tmax, Tmin, and AT35 HWDI for MAMJ 1993-2014 (in red) and for the real-time forecast of MAMJ 2016 (orange) over Sahel (10N-20N,10W-20E). ERA-Interim index is shown in blue.

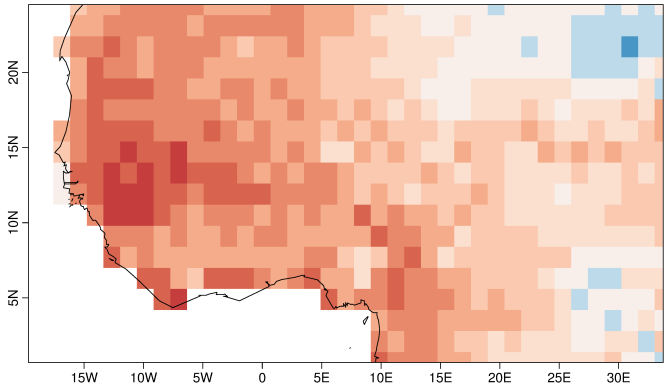
# S2S skill for apparent temperature (April 1993-2014)



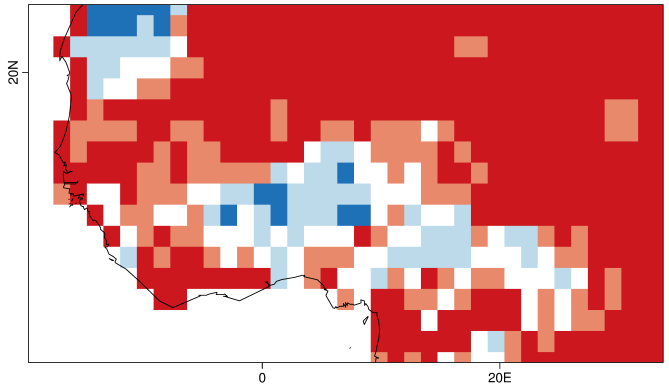

Weekly mean AT correlation against ERA-Interim according to lead time (weeks 1-4) for 1 and 15 April 1993-2014 re-forecasts with Météo-France S2S.

# Probability forecast verification for MAMJ 2016 season

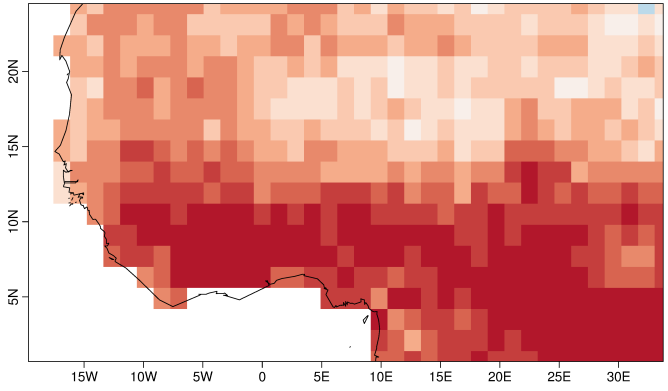
## P(Tmax HWDI > highest 20%)



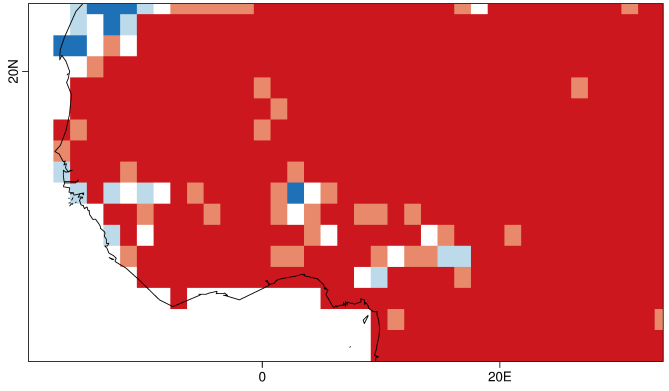

## ERA-Int Tmax HWDI obs. quintile

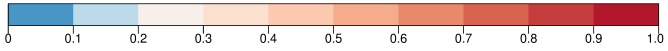


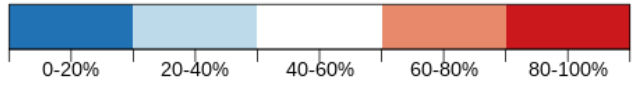

## P(Tmin HWDI > highest 20%)




## ERA-Int Tmin HWDI obs. quintile



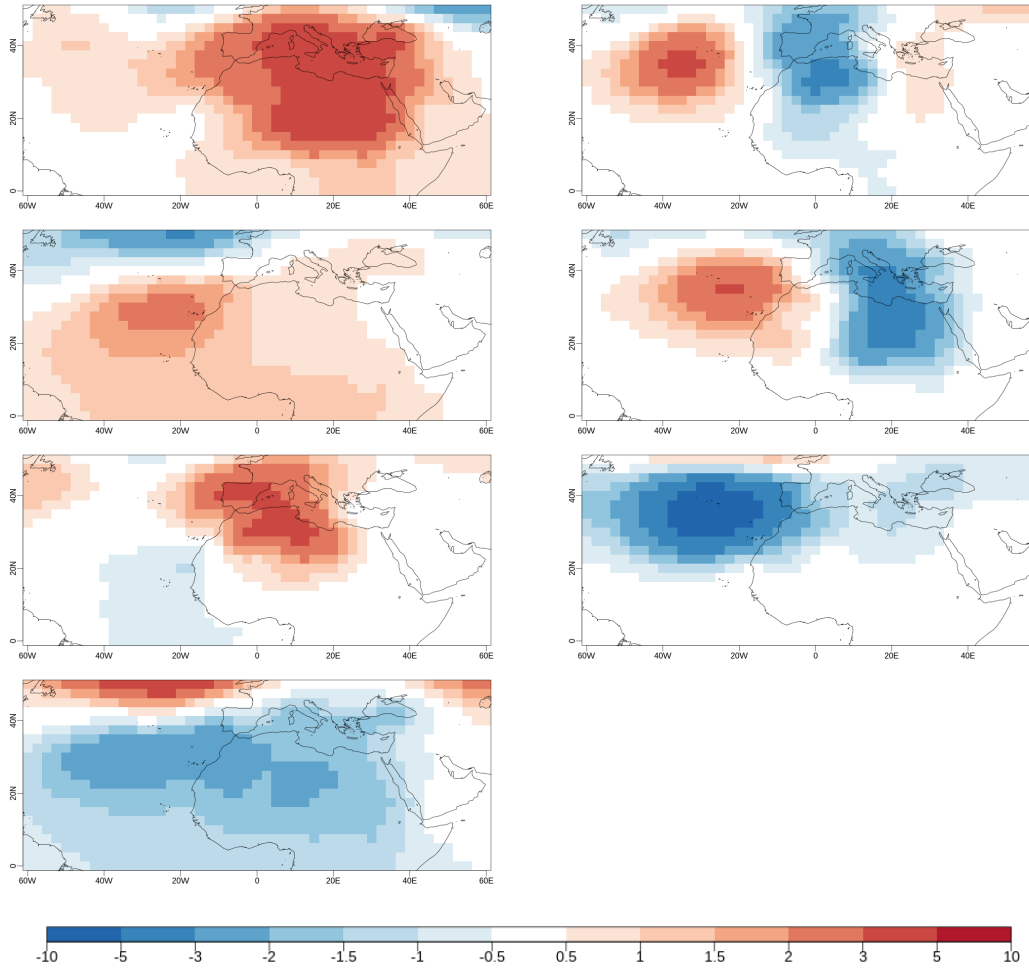



# Weather type approach

## Computation of weather types (V. Moron et al.)

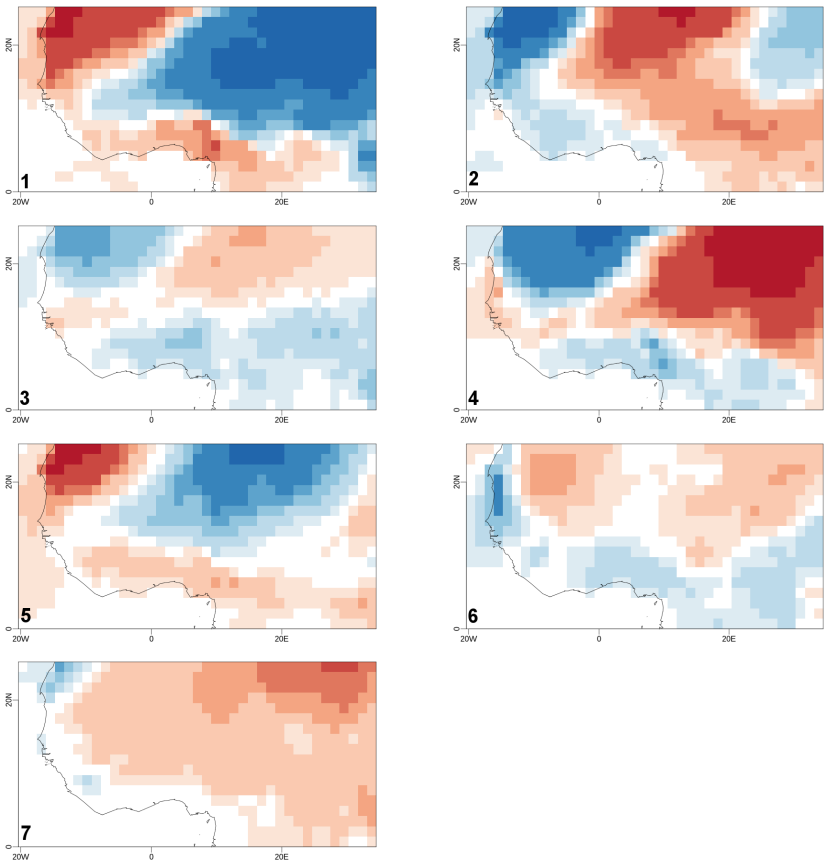
- Based on daily NCEP 925hPa wind and sea-level pressure anomalies for FMAMJ 1967-2014
- Slightly larger domain : [0-30N ; 40W-40E]
- PCA and k-means clustering approach
- Weather types 1 to 7 ranked according to corresponding mean thermal anomaly in station data over West Africa



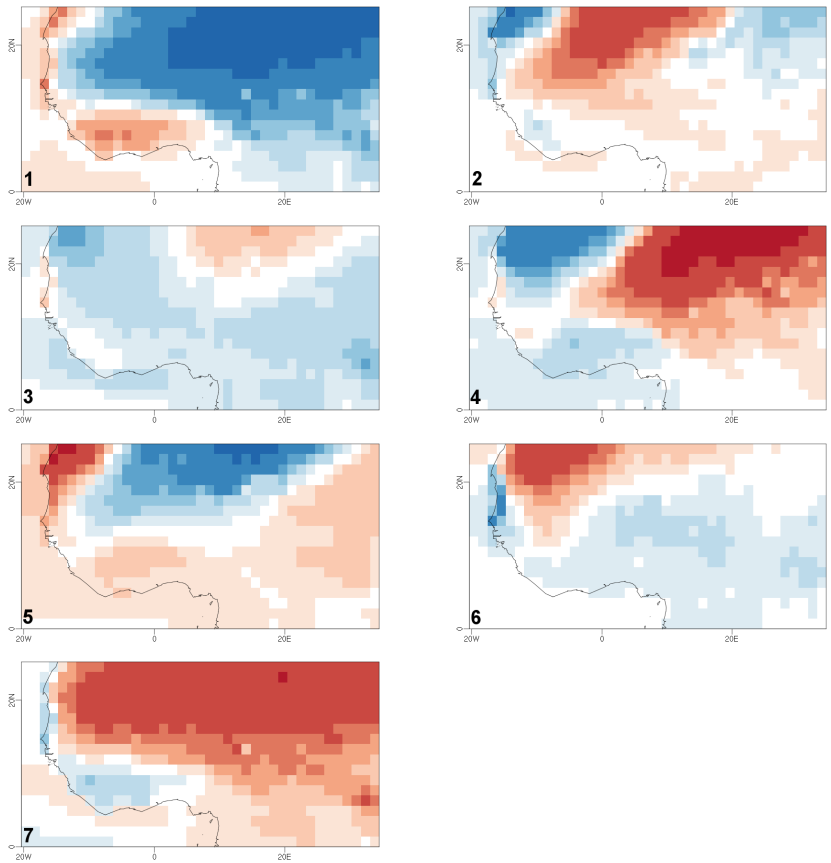

NCEP SLP anomaly composites for weather types 1 to 7 (hPa)

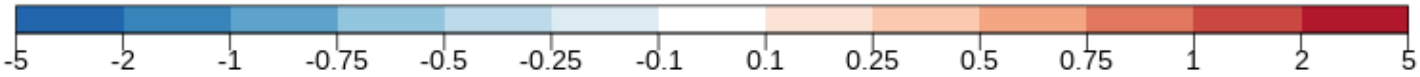
# Temperature anomaly composites - MAMJ

## ERA-Interim Tmax




## CNRM-CM Tmax

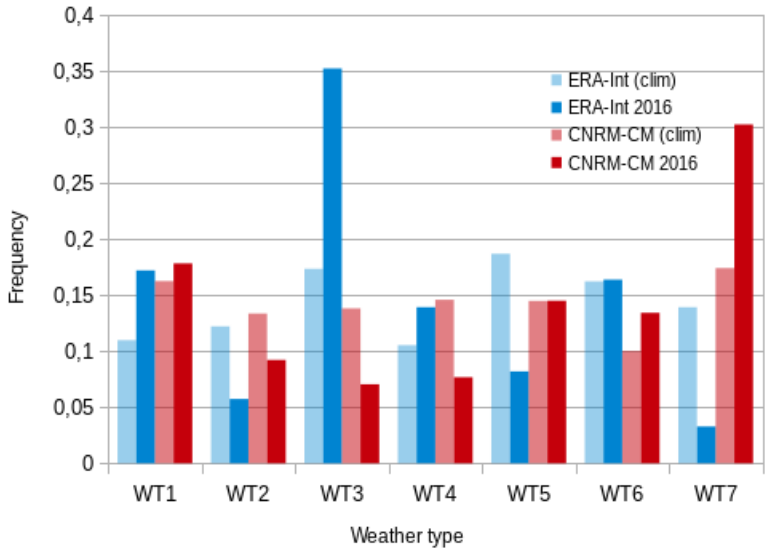


# Weather types in MAMJ 2016 season

## Weather type frequencies

- No skill in predicting weather type frequency anomalies
- A tool for understanding HW occurrence probabilities
- CNRM-CM fails to correctly simulate weather type duration (too short)




## MAMJ 2016 case study

- Anomalies in ERA-Interim data show more WT3 and less WT7
- WT3 has somewhat alleviated impact of 2015/16 El Niño
- CNRM-CM saw increased frequency of WT7, over-estimating warm temperatures in coastal areas

# S2S predictions : an April 2016 case study

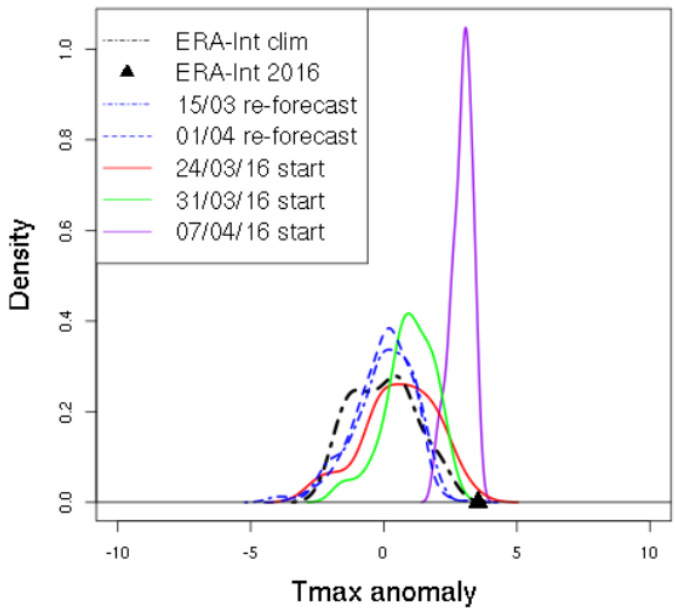
## Tmax and Tmin distributions

- Matam area (Senegal)
- Region around 15N - 12W (4 gridpoints)
- Model shows very limited skill in hindcast
- Focus : 12-22 April 2016 heat wave

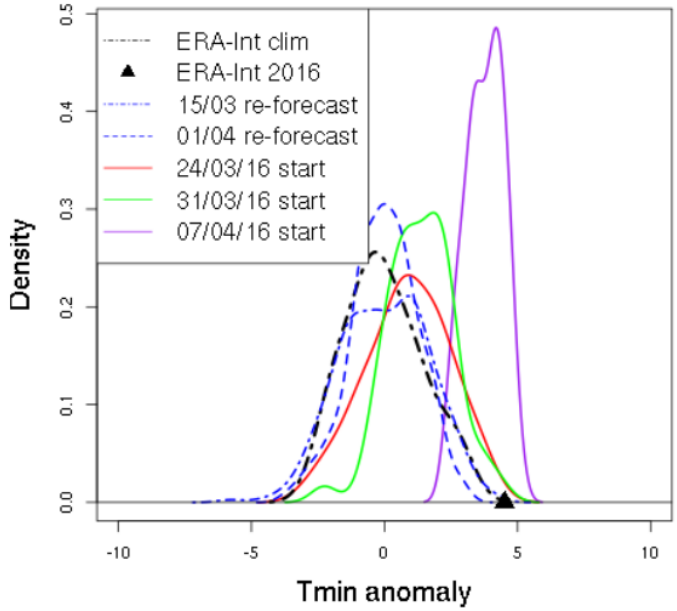
## Evolution with lead time

- Particularly high Tmin anomaly
- Distribution sharpens with reduced lead time
- Some anticipation of event 3 weeks ahead

**(a) Tmax**



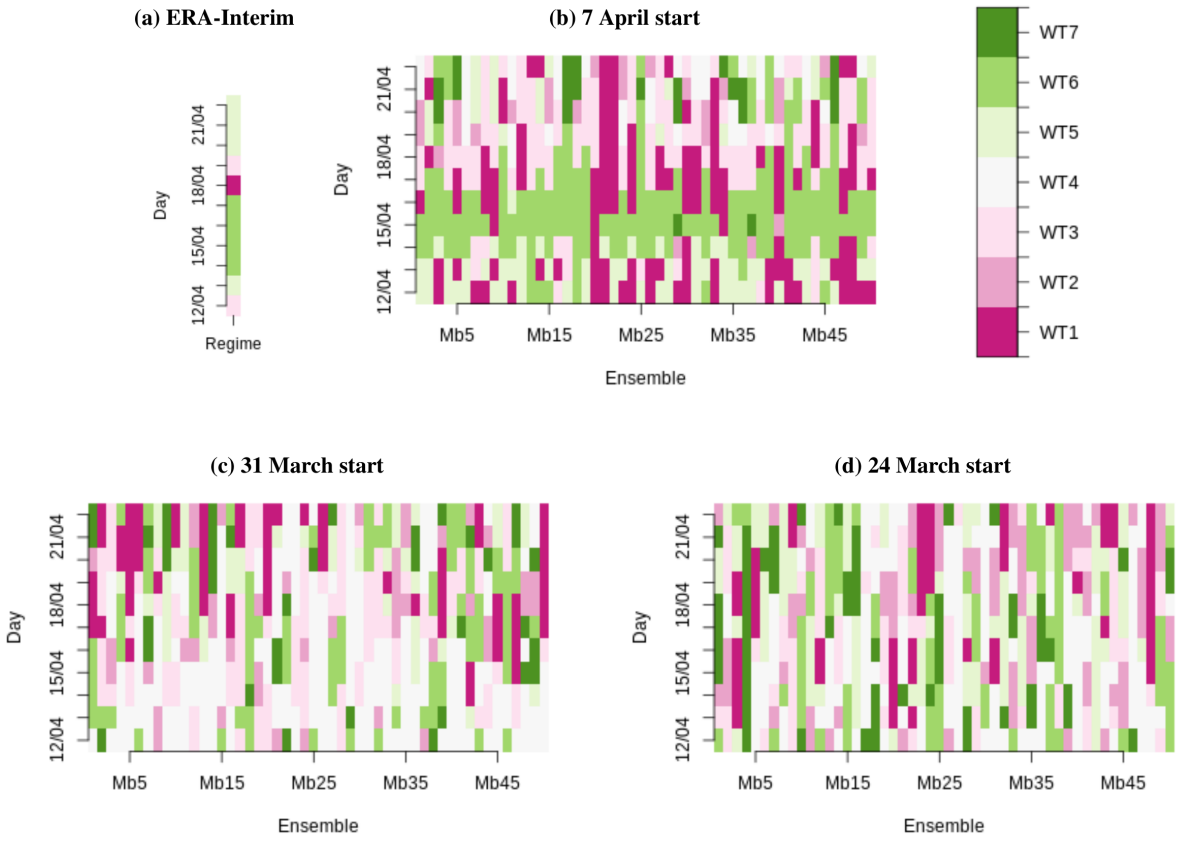

**(b) Tmin**



# Weather types for April 2016 case study

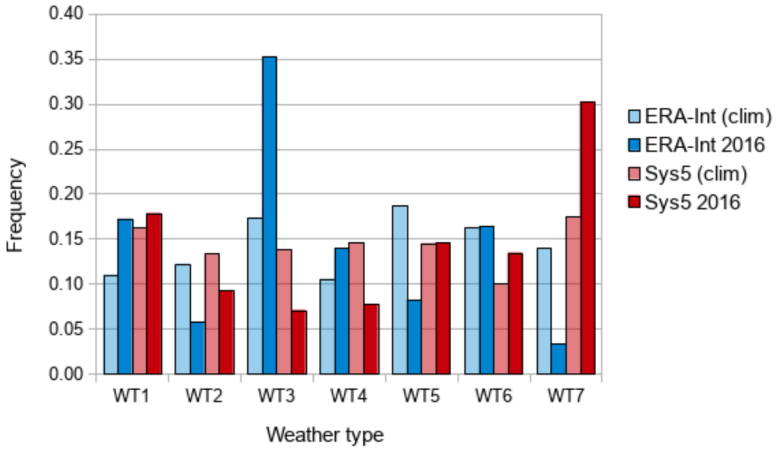
## "Klee diagrams" (Muñoz et al. 2016)

- Color-coding each WT
- Closest initialization already shows some spread between members
- WT6 anomaly not well captured by March start dates

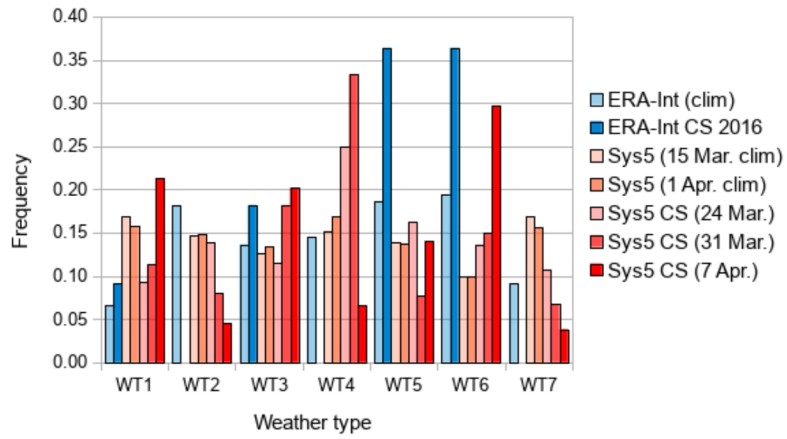


# Weather types between time scales

(a) MAMJ




(b) 12-22 April (CS)

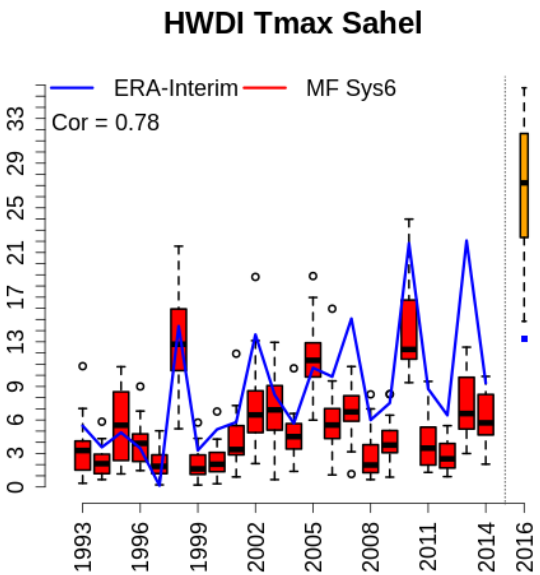



## An extreme event during an anomalously warm season

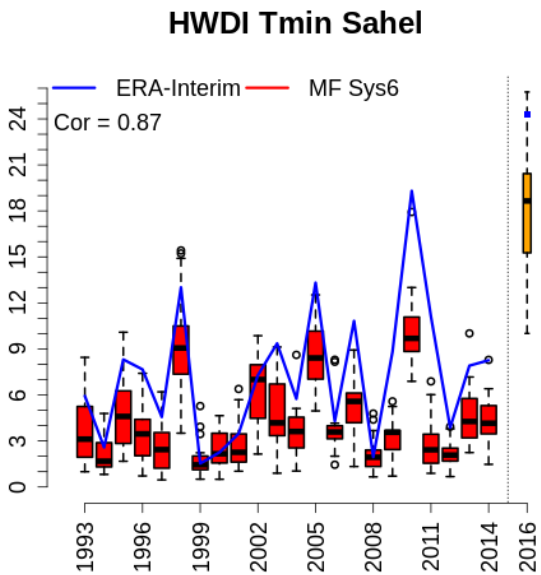
- But WT anomalies during the event are different from seasonal anomalies
- WT frequency biases often similar between S2S for 12-22 April and seasonal re-forecasts for MAMJ
- Not so true for the 2016 case study : inter-seasonal variability
- Some anomalies for 12-22 April are only captured 1 week ahead (ex : WT4)

# Do conclusions hold for Météo-France System 6 ?

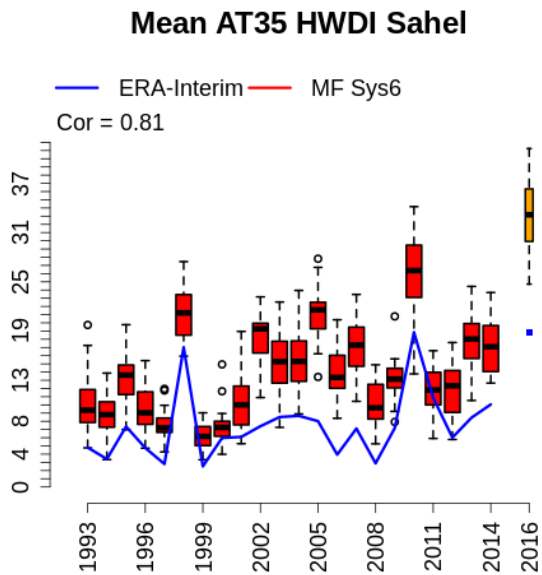
## (a) Tmax HWDI




## (b) Tmin HWDI




## (c) AT35 HWDI




Box-and-whisker plots of the ensemble reforecasts of Tmax, Tmin, and AT35 HWDI for MAMJ 1993-2014 (in red) and for the re-forecast of MAMJ 2016 (orange) over Sahel with System 6. ERA-Interim index is shown in blue.

# Main conclusions

## Predictability of heat waves with Météo-France system 5

- Challenging region, time of year and forecast lead times
- Limited seasonal prediction skill for heat wave indices (in line with Tmax and Tmin skill)
- Sub-seasonal prediction skill remains fairly limited over the region
- At a regional scale, forecast for MAMJ 2016 was quite informative (conditional skill ?)

## Beyond model limitations ?

- System 5 exhibits strong biases and poor skill in radiative fluxes and cloud cover over the region
- Using WTs as predictors would likely lead to no gain in skill with respect to direct model output for temperature

Batté L., C. Ardilouze and M. Déqué (2018) Forecasting West African Heat Waves at Subseasonal and Seasonal Time Scales. *Monthly Weather Review,* **146** 889–907. DOI : 10.1175/MWR-D-17-0211.1

# Thank you for your attention !

For more information on the ACASIS project : https ://acasis.locean-ipsl.upmc.fr/

# References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