Sudden stratospheric warmings in reanalyses and their tropospheric fingerprint

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SSWs: introduction

- Key phenomena of the wintertime polar stratospheric variability with effects beyond the stratosphere.

A better understanding and model representation of SSWs processes would help to improve medium-long range surface weather forecasts.

Two aspects to focus on:

- Representation of SSWs in reanalyses
- Case study: SSW 2018 and its role in the high rainfall event in Southwestern Europe

1st aspect:
How close is the agreement across reanalyses in the representation of SSWs?

S-RIP initiative

Ayarzagüena, B., F. M. Palmeiro, D. Barriopedro, N. Calvo, U. Langematz, and K. Shibata, 2019: On the representation of major stratospheric warmings in reanalyses, Atmos.Chem. Phys., 19, 9469-948.

Data

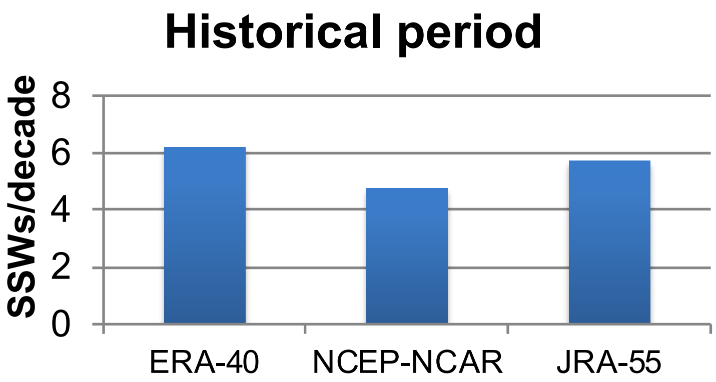
Periods of study and reanalyses:

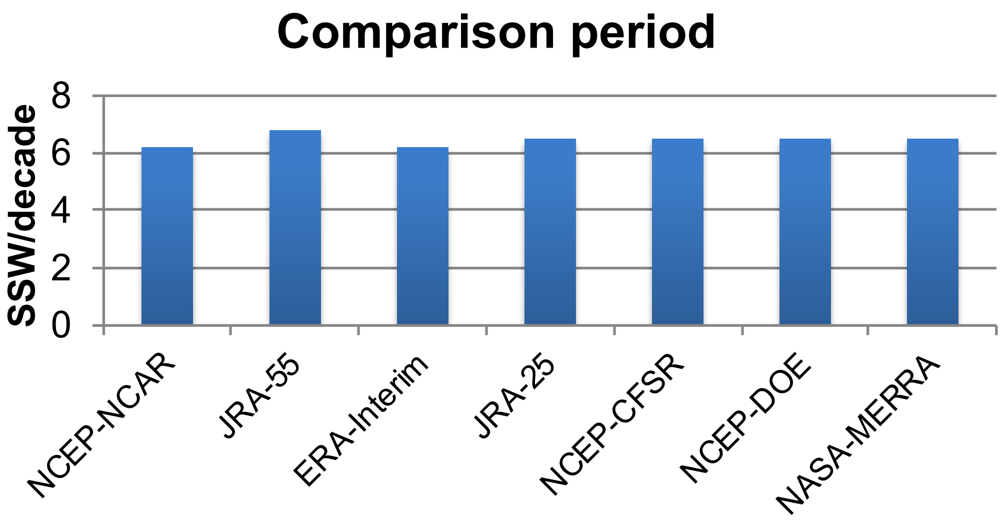
- Historical period: 1958-1978: NCEP-NCAR, ERA-40 & JRA-55.
- Comparison period: 1979-2012: NCEP-NCAR, JRA-55, ERA-Interim, JRA-25. NCEP-CFSR, NCEP-DOE, NASA-MERRA.

Multi-Reanalysis Mean (MRM)

- **Historical period:** average of all reanalyses in the 20-yr period.
- **Comparison period:** average of ERA-Interim, NCEP-CFSR, JRA-55, NASA-MERRA in the period 1980-2010.

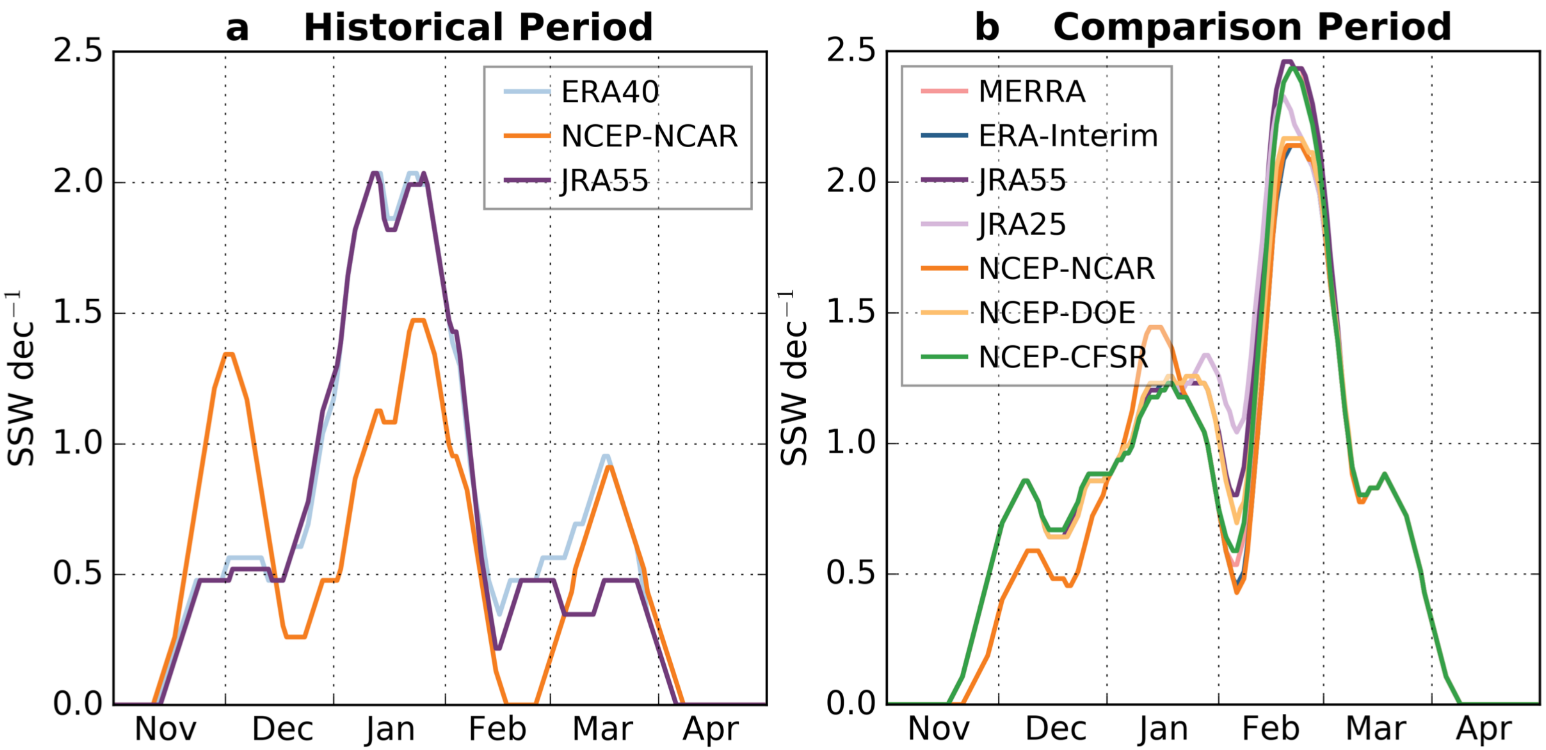
Frequency of SSWs (WMO criterion)





- **Historical period:** largest differences between reanalyses
  - Similar results for ERA-40 and JRA-55.
  - NCEP/NCAR: Lower SSW frequency.
- **Comparison period:** general agreement

Seasonality of SSWs (WMO criterion)



SSW frequency distribution within ±10 day periods

- Different seasonality of SSWs in historical and comparison period.
- **Historical period:** largest differences between reanalyses
  - Similar results for ERA-40 and JRA-55.
  - NCEP/NCAR: Different seasonal distribution

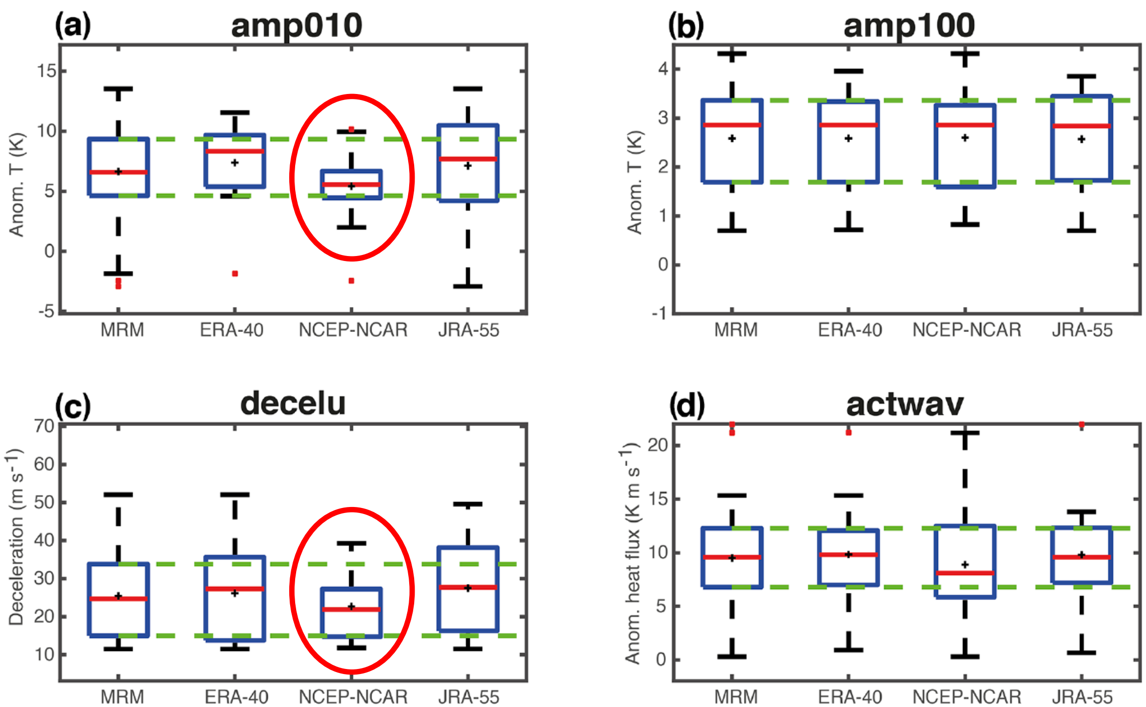
Process-based diagnostics of SSWs

Same SSWs considered in all reanalyses (SSW based on reversal of $[u]_{60N}$ at 10hPa)

Historical period

Amplitude of warming @ 10hPa
Area-weighted 10-hPa polar cap T anom. ±5 days around SSW date

Amplitude of warming @ 100hPa
Area-weighted 100-hPa polar cap T anom. ±5 days around SSW date



Decel. PNJ @ 10hPa
Dif. in 10-hPa ū at 60°N, -15/-5 days minus 0/+5 days of SSW date

Preceding wave activity @100hPa
Area-weighted 100-hPa meridional eddy heat flux anom. (45°-75°N), -20/0 days of SSW date.

Charlton & Polvani (2007)

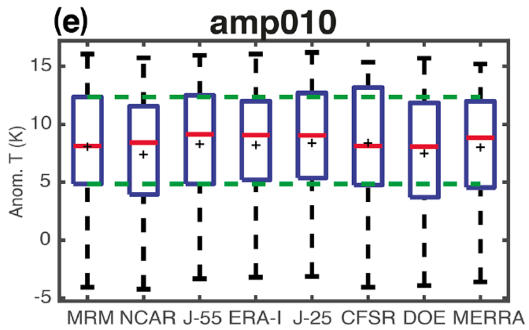
- General good agreement in all benchmarks in all reanalyses.
- NCEP/NCAR deviates the most from the other datasets for diagnostics at 10hPa

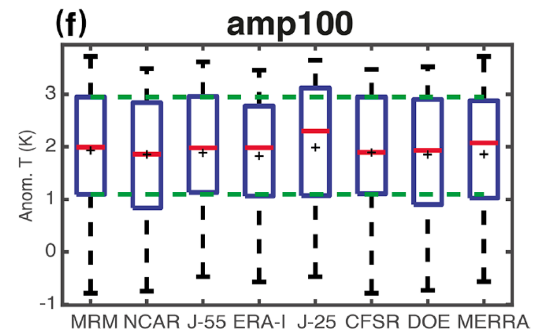
Process-based diagnostics of SSWs

Same SSWs considered in all reanalyses (SSW based on reversal of $[u]_{60N}$ at 10hPa)

Comparison period

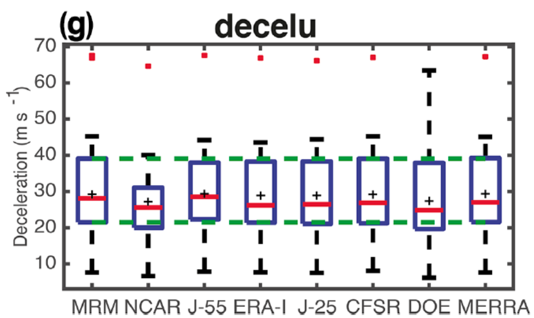
Amplitude of warming @ 10hPa
Area-weighted 10-hPa polar cap T anom. ±5 days around SSW date

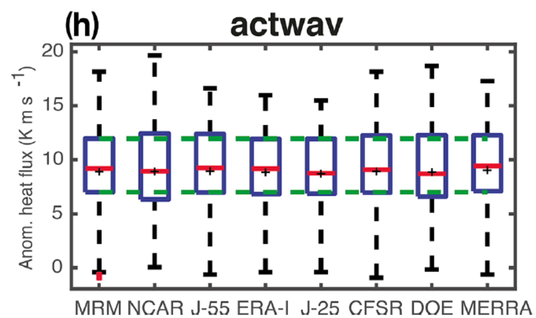




Amplitude of warming @ 100hPa
Area-weighted 100-hPa polar cap T anom. ±5 days around SSW date

Decel. PNJ @ 10hPa
Dif. in 10-hPa $\bar{u}$ at 60°N, -15/-5 days minus 0/+5 days of SSW date





Preceding wave activity @100hPa
Area-weighted 100-hPa meridional eddy heat flux anom. (45°-75°N), -20/0 days of SSW date.

- SSWs characteristics are similar in both periods.
- General good agreement in all benchmarks in all reanalyses.

Process-based diagnostics of SSWs

Same SSWs considered in all reanalyses (SSW based on reversal of $[u]_{60N}$ at 10hPa)

Historical period

Amplitude of warming @ 10hPa
Area-weighted 10-hPa polar cap T anom. ±5 days around SSW date

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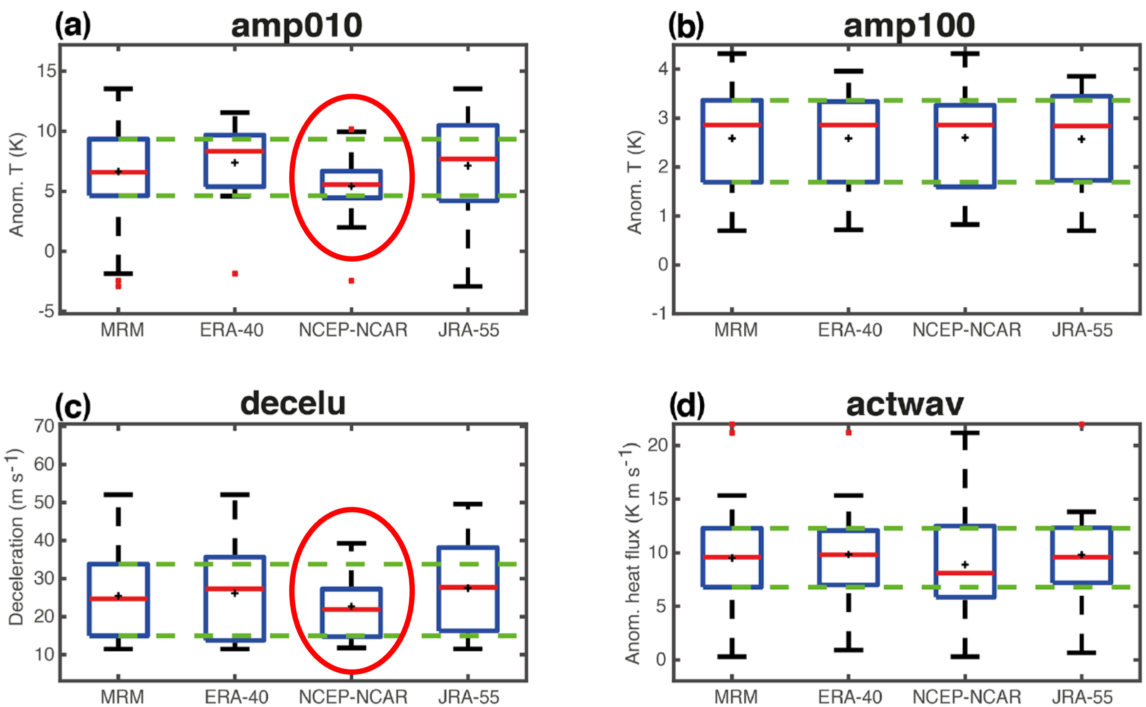
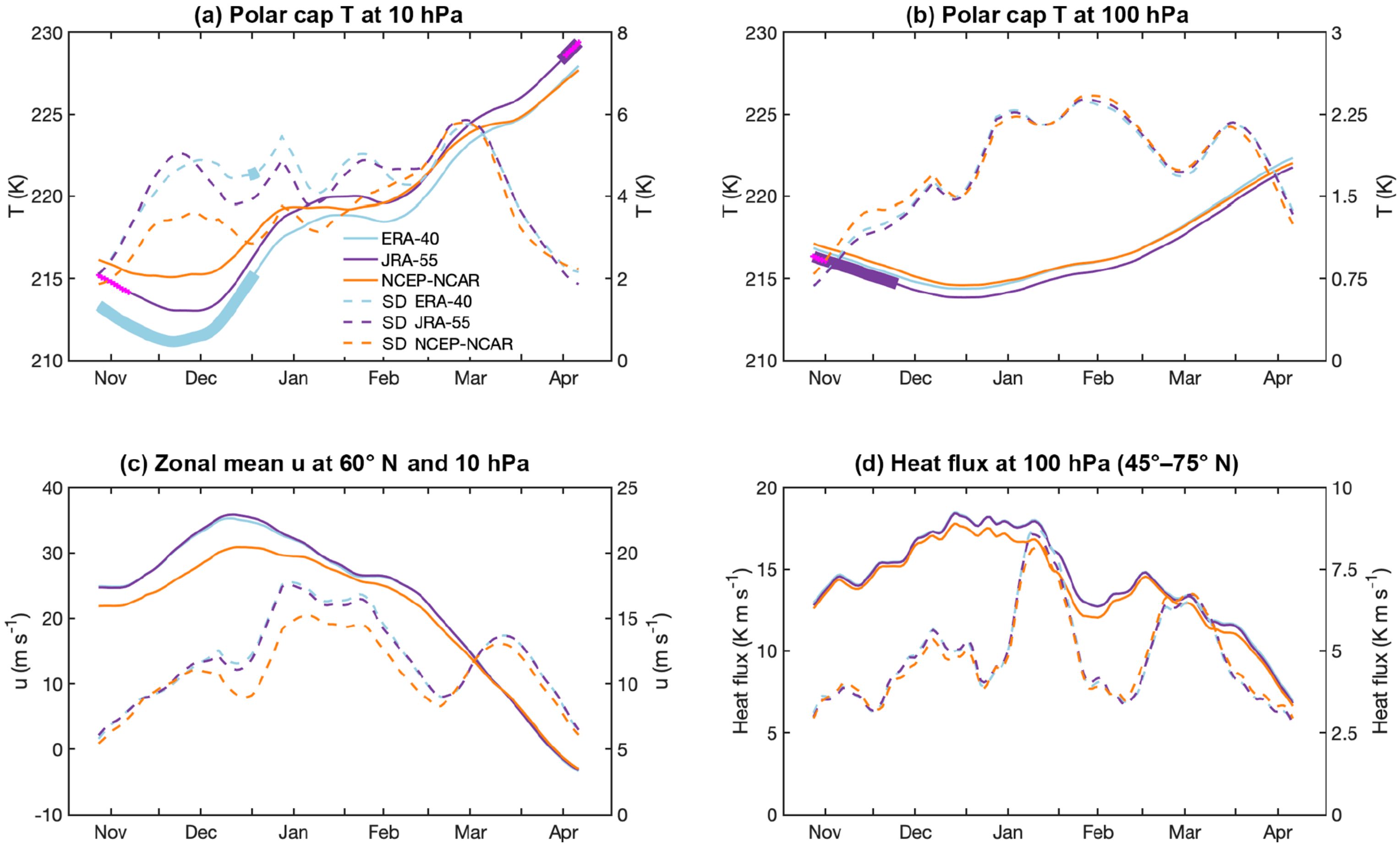


Charlton & Polvani (2007)

- General good agreement in all benchmarks in all reanalyses.
- NCEP/NCAR deviates the most from the other datasets for diagnostics at 10hPa and particularly, in the historical period → effects of 10hPa top of the model.

Process-based diagnostics of SSWs

Climatologies in historical period

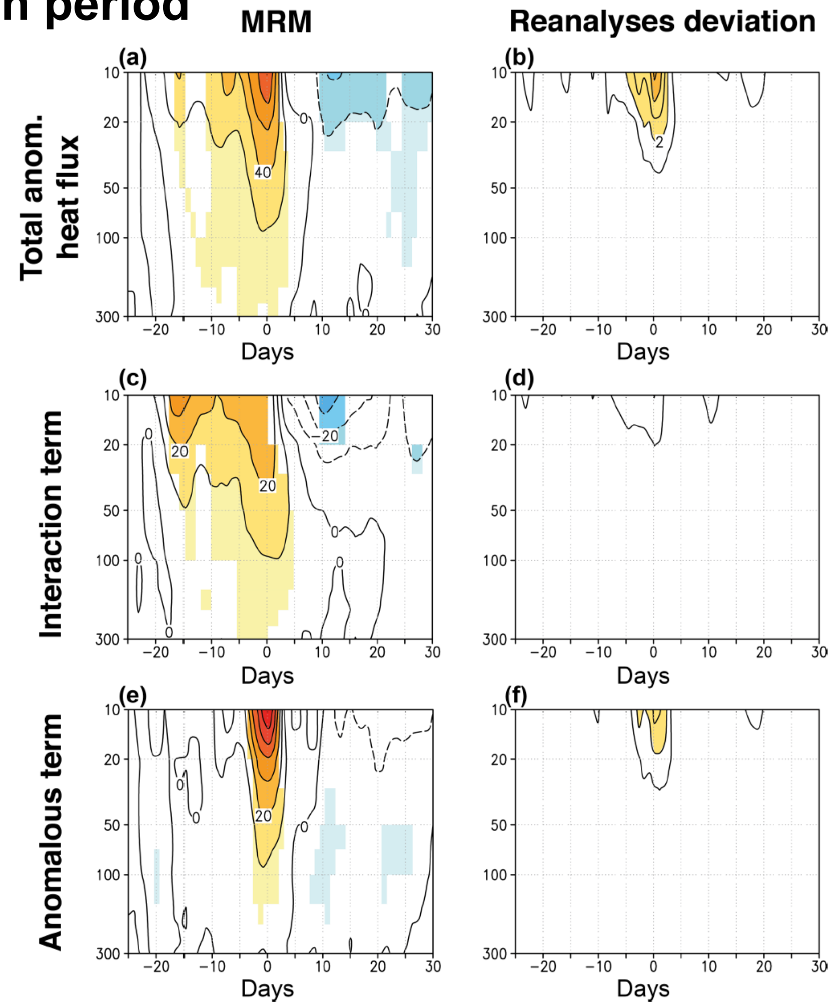


- Very good agreement across reanalyses in variables at 100hPa.
- Largest differences at 10hPa in mean state and variability particularly between NCEP/NCAR and the other two (JRA-55 and ERA-40) → effects of 10hPa top of the model.

Dynamical forcing: Upward-propagating wave activity

Comparison period

- SSWs are mainly associated with anomalous wave packets immediately before their onset.
- Interference with climatological stationary waves plays a predominant role several days before the SSW onset.
- This behavior is robust across reanalyses during the comparison period.



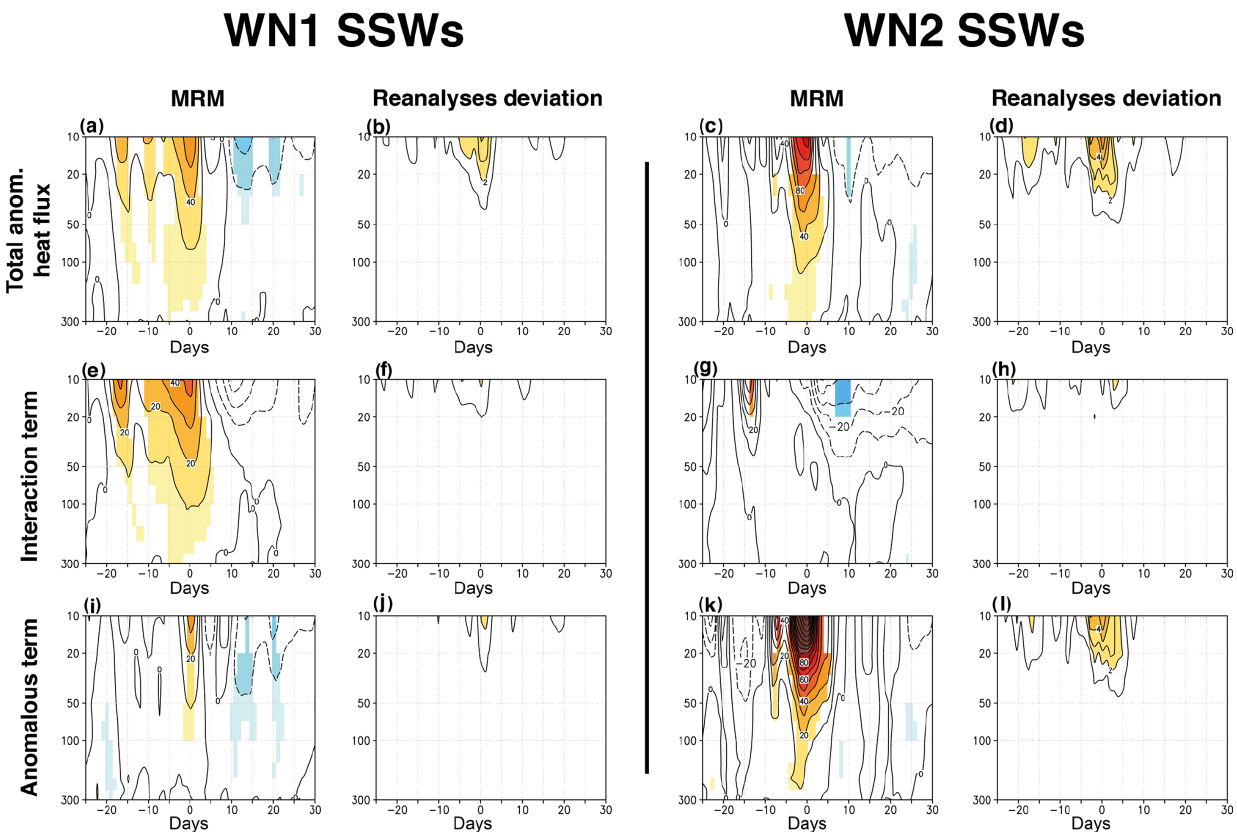
Shading: stat. significant anomalies at 95% confidence level (Monte Carlo test) in at least 66.7% of reanalyses

$$[v^*T^*]_a = [v_a^*T_a^*]_a + [v_c^*T_a^*] + [v_a^*T_c^*]$$

NONLINEAR TERM: Term attributed to wave anomalies

INTERACTION TERM: Interference between climatological planetary waves and wave anomalies

Dynamical forcing: Upward-propagating wave activity



•<u>WN1 SSWs</u>: persistent moderate $[v^*T^*]_a$ from -20 days prior to SSW ← interaction term

•<u>WN2 SSWs</u>: intense but short pulses of $[v^*T^*]_a$ in [-10, 0] days prior to SSWs ← anomalous term.

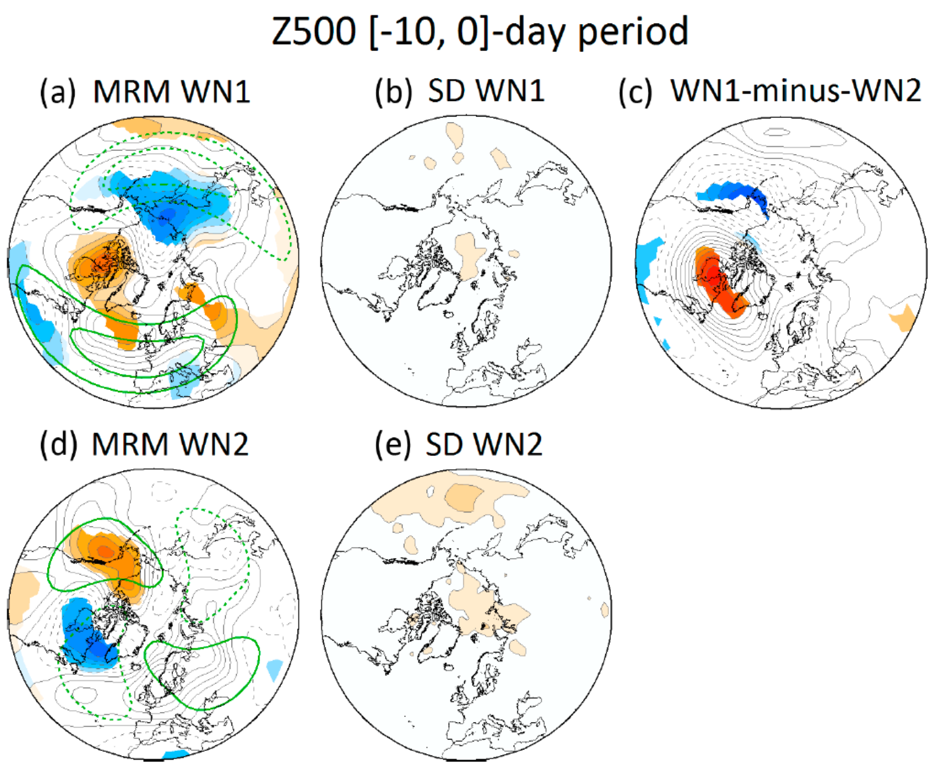
All datasets can reproduce the different mechanisms involved in WN1 and WN2 SSWs. The spread is higher for WN2 SSWs than for WN1 SSWs.

Based on daily 50 hPa geopotential height data at 60ºN into wave-1 (Z_1) and wave-2 (Z_2)

- <u>WN2 SSW:</u> $[Z_2] \geq [Z_1]$ averaged for the [-10,0]-day prior to SSW; or $Z_2 - Z_1 \geq 200$ m at least for one day within the [-10,0]-day prior to SSW.
- <u>WN1 SSW:</u> other SSWs.

Dynamical forcing: Tropospheric circulation anomalies

Shading: stat. significant anomalies at 95% confidence level (Monte Carlo test) in at least 66.7% of reanalyses

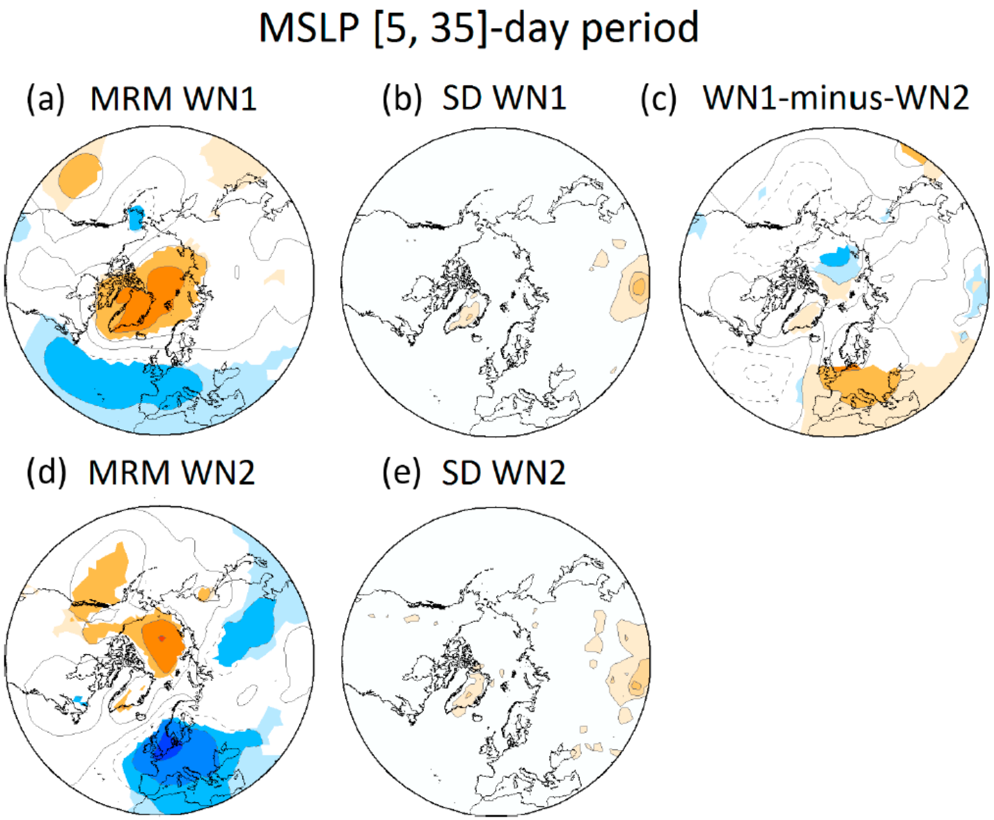


Shading: stat. significant differences at 95% confidence level (Monte Carlo test) in at least 66.7% of reanalyses

- Statistically significant differences between the precursors of WN1 and WN2 SSWs.
- **WN1 SSWs:** WN1-like structure over antinodes of climatological WN1 wave → constructive interference
- **WN2 SSWs:** Anomalous centers coincide with antinodes of climatological WN2. → Constructive interference amplified in the stratosphere (resonance).
- Very good agreement across reanalyses.

Surface signal of SSWs

Shading: stat. significant anomalies at 95% confidence level (Monte Carlo test) in at least 66.7% of reanalyses



Shading: stat. significant differences at 95% confidence level (Monte Carlo test) in at least 66.7% of reanalyses

- WN1 and WN2 SSWs have significant impacts on surface weather (NAO -) but with some differences in southern and central Europe.
- These differences are significantly different between WN1 and WN2 events and robust across reanalyses during the comparison period.

Brief summary

- There is a general agreement in main characteristics (frequency, seasonality and dynamical benchmarks) of SSWs across reanalyses in both periods.

- However, discrepancies are larger in the pre-satellite period than afterwards, particularly for the NCEP/NCAR reanalysis → effect of low-top model.

- A good agreement among reanalyses is found for triggering mechanisms and surface fingerprint in the comparison period specifically for WN1 & WN2 SSWs.

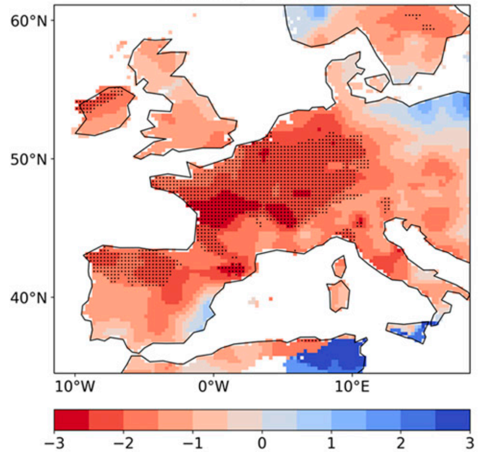
2nd aspect:
Case study: Were rainy conditions in Southwestern Europe and the SSW in 2018 related?

Ayarzagüena, B., D.Barriopedro, J.M. Garrido-Perez, M.Abalos, A. De la Cámara, R.García-Herrera, N.Calvo and C. Ordoñez: Stratospheric connection to the abrupt end of the 2016/2017 Iberian drought. *Geophys. Res. Lett.*, 45, doi: 10.1029/2018GL079802

Introduction

- The most severe drought in Europe in 2016-2017 since 1979 that persisted until early 2018 in Southwestern Europe, when extraordinary rainy conditions replaced them.

Drought index
Jul2016/Jun2017



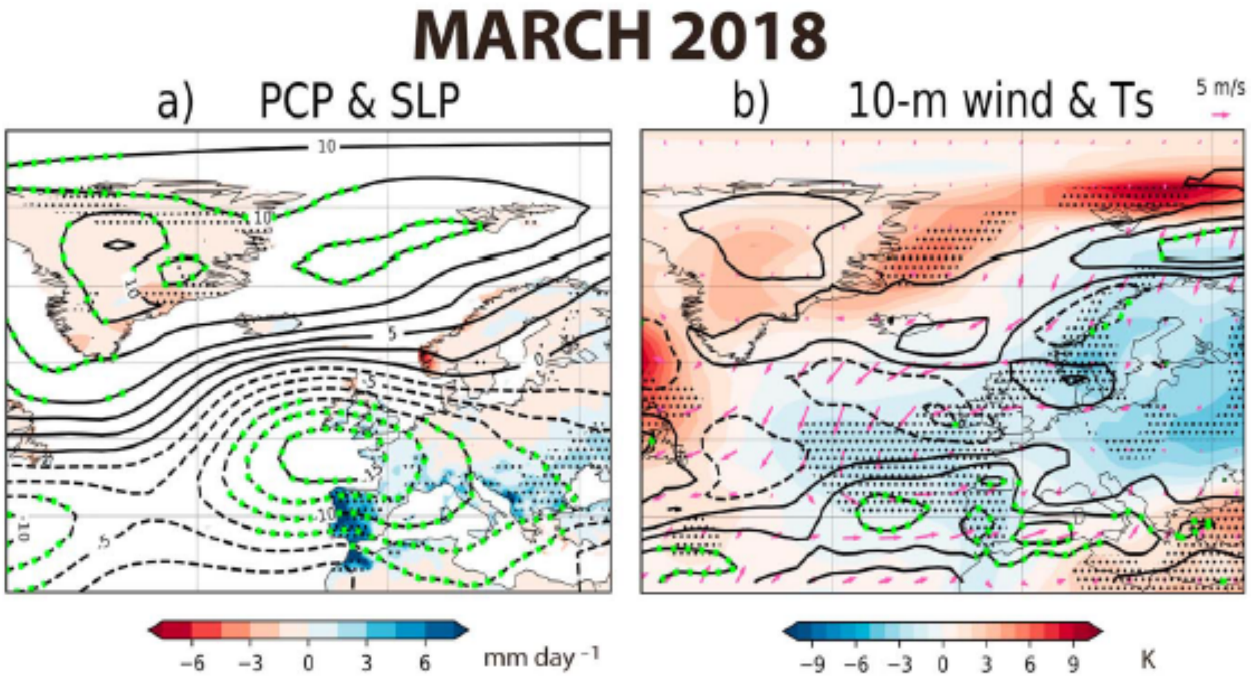
García-Herrera et al. (2019)

- A sudden stratospheric warming (SSW) took place in mid-February 2018.

Data

- Daily means from NCEP/NCAR reanalysis
- Daily precipitation totals from Climate Prediction Center Global Unified Precipitation database.
- Period: 1979-2018.

Weather conditions in Southwestern Europe in March 2018



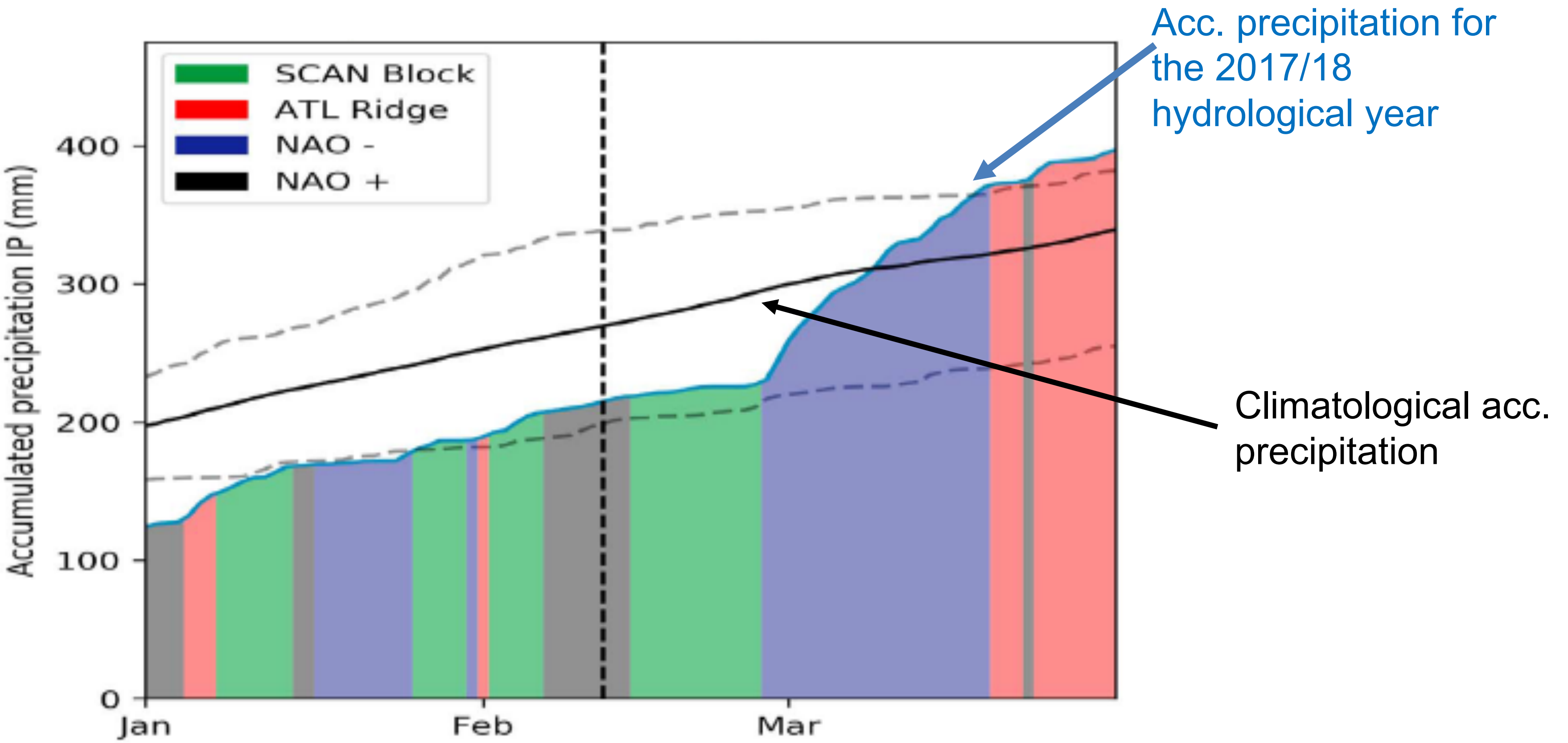
PCP (shading) & SLP (contours)   Ts (shading) & wind (contours & arrows)

Green contours and dotted shading: anomalies above |±1.5σ|

- Extraordinary windy and rainy conditions in Western Mediterranean area:
  - Anomalies above 1.5 σ
  - Precipitation totals in March in Spain hitting record values
- Large scale SLP conditions associated with NAO-

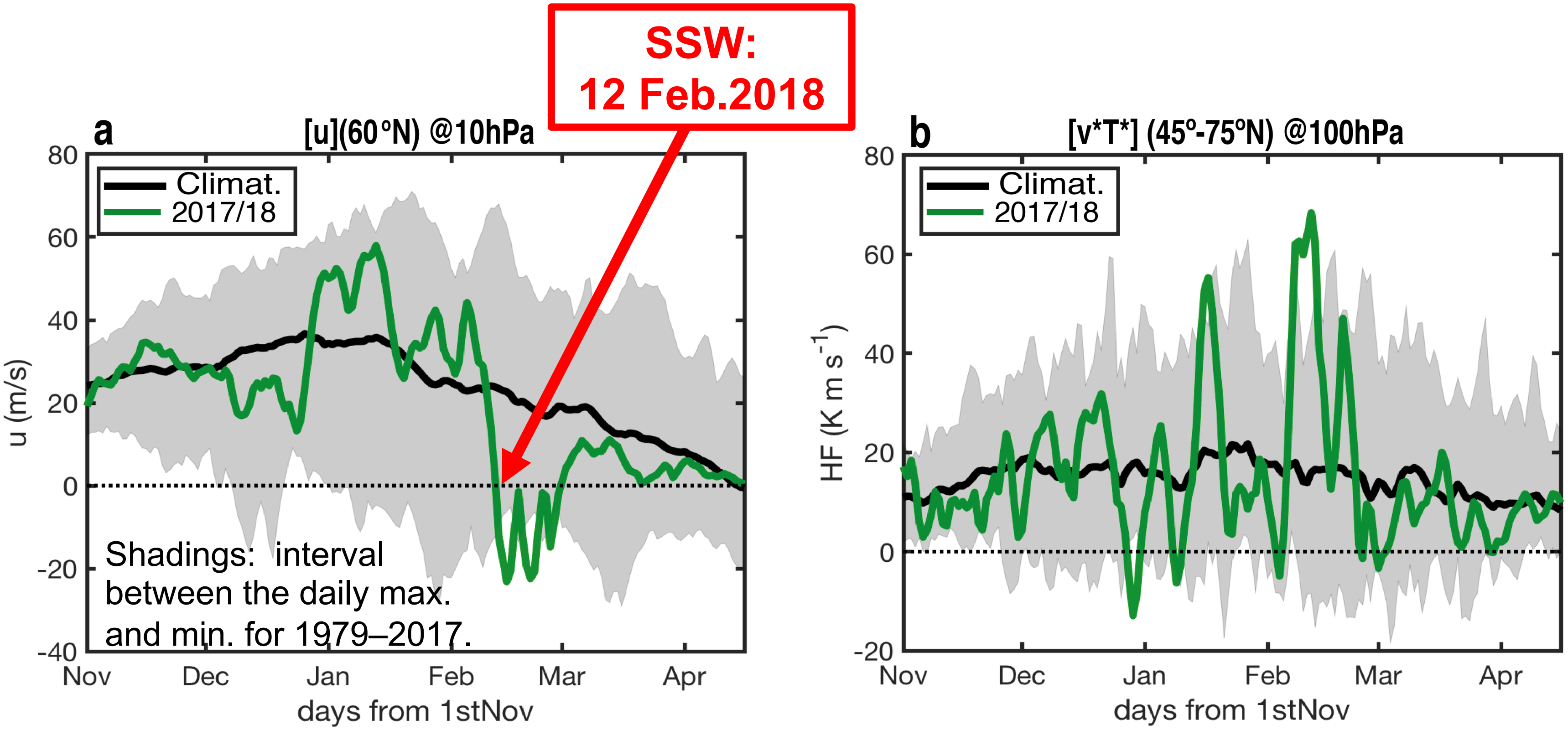
Weather conditions in Southwestern Europe in March 2018

Daily sequence of Weather Regimes over Euro-Atlantic area and precipitation over Iberian Peninsula



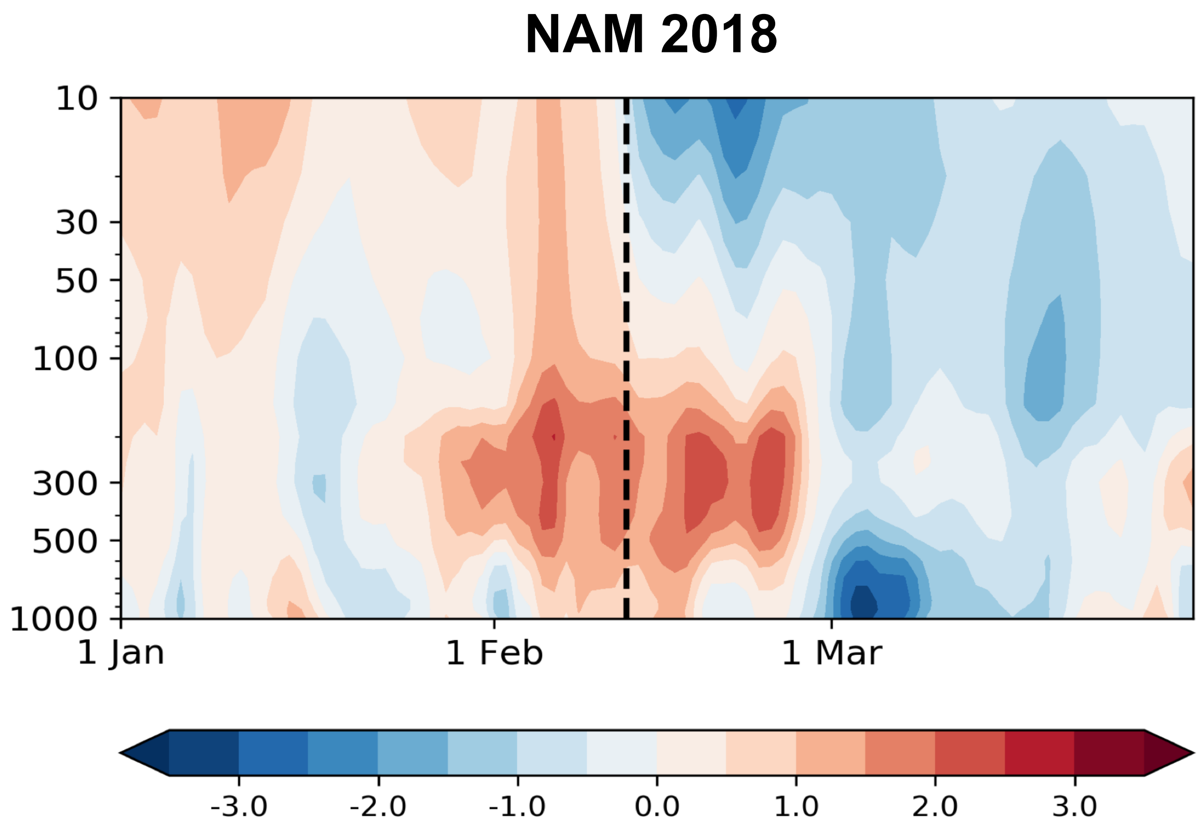
- Extraordinary weather conditions associated with NAO- WR.
- Shift to NAO- simultaneous to an abrupt rise of rainfall over the Iberian Peninsula.

Polar stratospheric state in early 2018



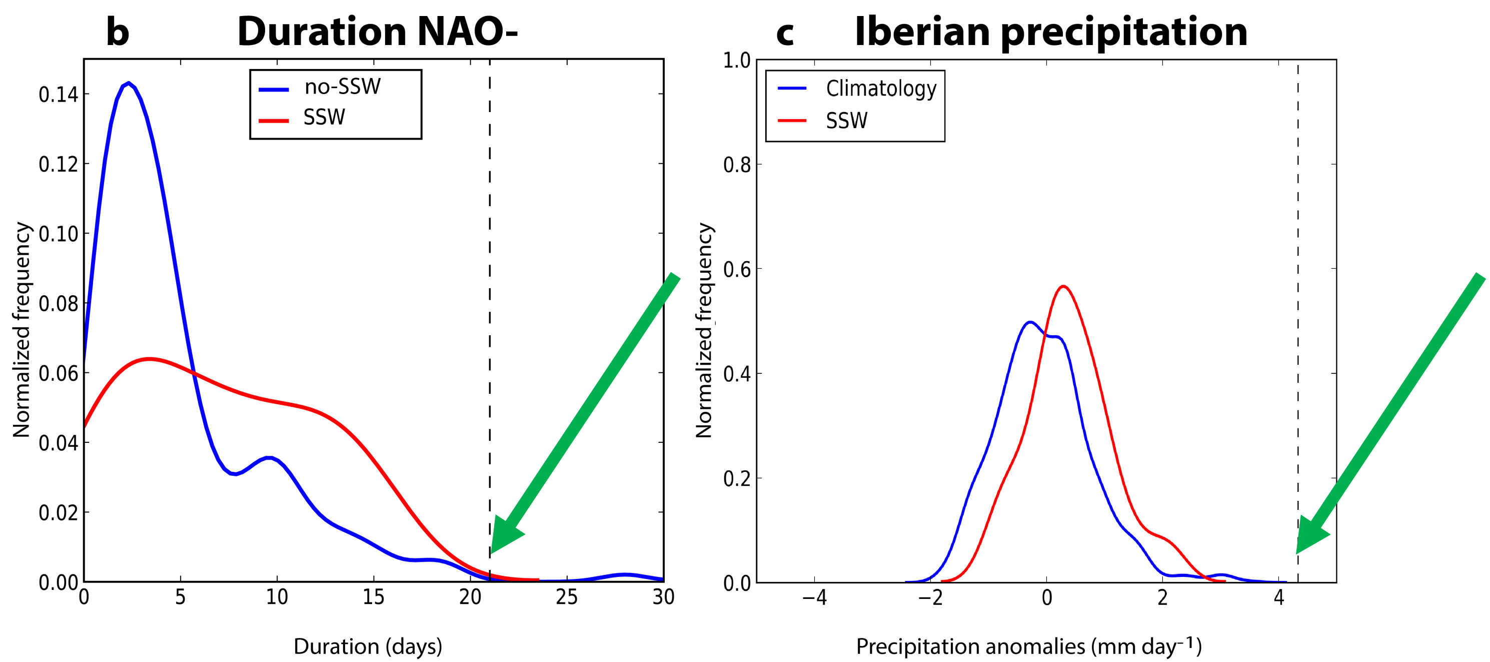
- A very intense and persistent SSW took place on 12 February 2018.
    - Easterly winds at 60N and 10hPa reached the highest values ever measured at that time of the year and were very persistent (16 days vs 7.6 ± 1.9 days, climatology)
- **Record-breaking** extratropical wave activity @ 100 hPa in early February.

Evidences for the stratosphere-troposphere connection



The negative NAM values (SSW signal) propagated downward reaching the troposphere timely with a tropospheric WR shift to NAO−: stratospheric influence

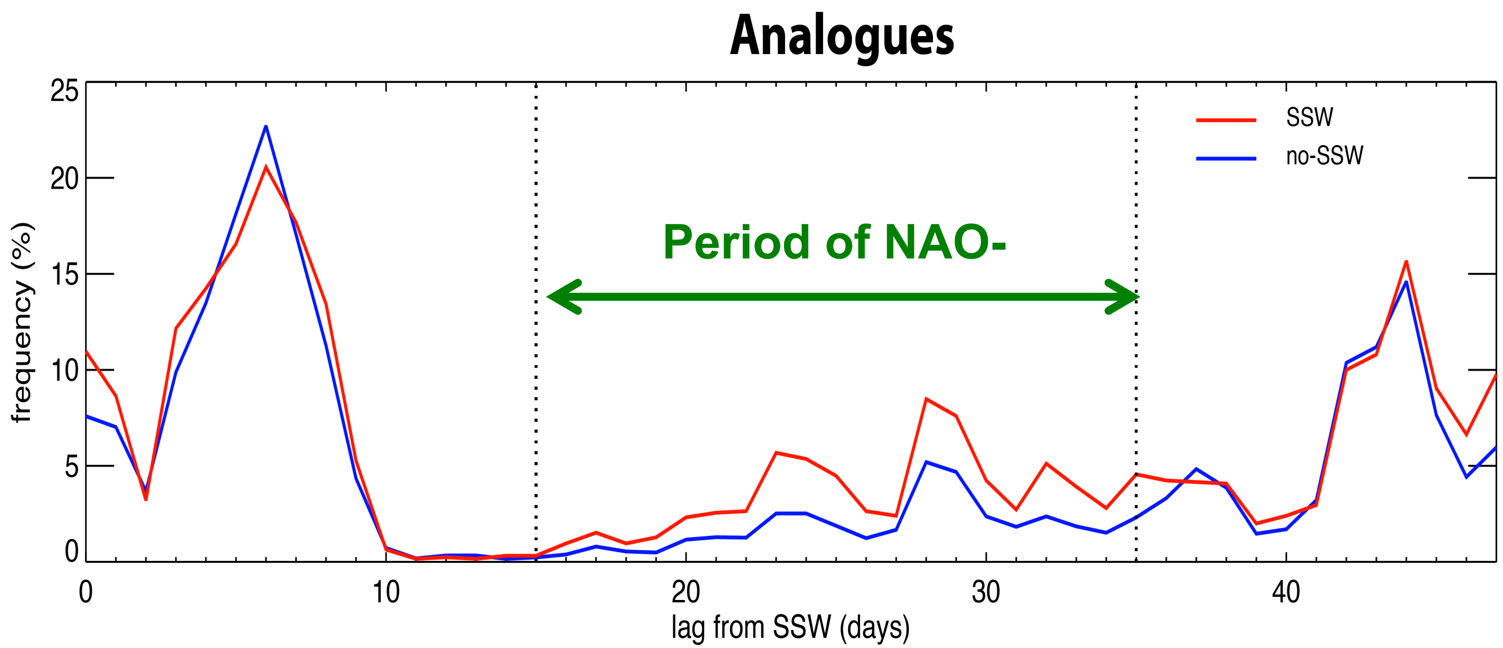
Evidences for the stratosphere-troposphere connection



Occurrence of conditions with higher probability during SSWs:

- Very persistent NAO − event after 2018 SSW (21 days) → consistent with preference of that WR after SSWs.
- Rainy conditions over Iberia after the 2018 SSW (the probability of above-average Iberian precipitation conditioned on the occurrence of an SSW is significantly higher than the climatology).

Evidences for the stratosphere-troposphere connection



Although extraordinary, the <u>2018 synoptic conditions are better reproduced by those occurring after SSWs</u> than in the remaining pool of winter days.

Brief summary

- Outstanding stratospheric and tropospheric conditions occurred in late winter 2018, with a persistent SSW and extreme Iberian precipitation.

- The 2018 SSW played a relevant role in the shift to and maintenance of the negative NAO event that ended the severe Iberian drought.

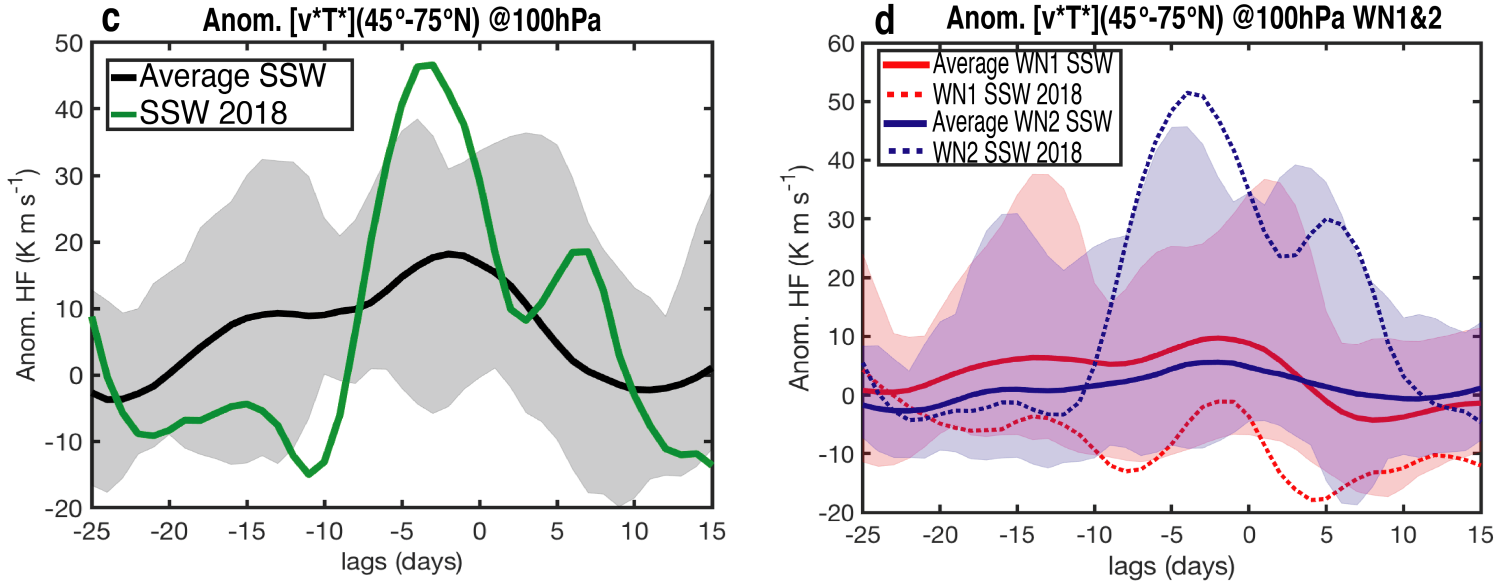
- The 2018 SSW is a good example of the stratosphere-troposphere dynamical coupling

Main conclusion

- There is a good agreement across reanalyses on representing SSWs and related processes.

- SSWs can modulate tropospheric circulation and so, including stratospheric information in middle-long range predictions can ultimately help to improve seasonal forecast predictions.

Polar stratospheric state in early 2018



Shadings: interval between the daily maximum and minimum of each field for 1979–2017.

Precursory wave activity:

- **Record-breaking** extratropical wave activity @ 100 hPa prior to SSW: the strongest one preceding the SSWs of the period.
- Main contribution to the wave activity: the largest wave number 2 (WN2) component of the period → split of the polar vortex into 2 pieces.