Diagnosing climate trends in sub-seasonal and seasonal hindcasts

Steffen Tietsche[1*], Michael Mayer[1,2], Antje Weisheimer[1,3,4], Frederic Vitart[1], Magdalena Balmaseda[1]

(1) European Centre for Medium-Range Weather Forecasts (ECMWF); (2) Department of Meteorology and Geophysics, University of Vienna; (3) NCAS; (4) AOPP, University of Oxford; (*) steffen.tietsche@ecmwf.int

Motivation

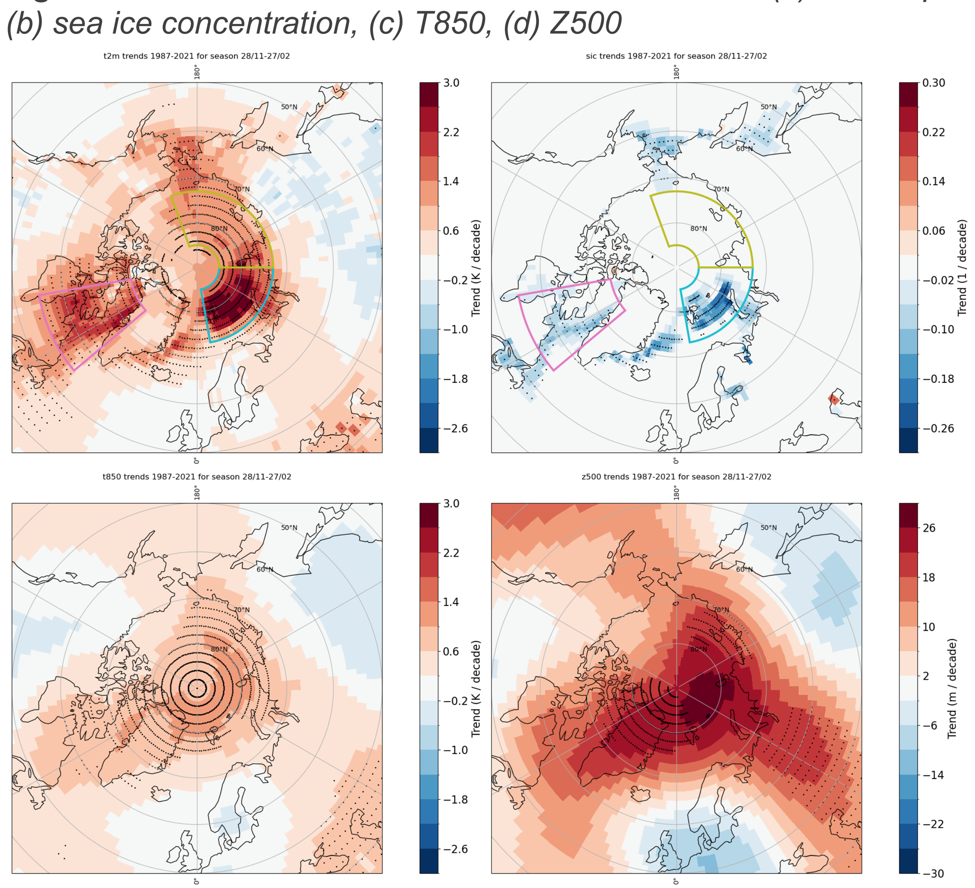
Climate trend errors across a sub-seasonal or seasonal set of hindcasts degrade forecast skill and point to deficiencies of the analysis/forecast system in representing the changing mean state or slow modes of natural variability. Hence, diagnosing these trend errors and understanding their source can provide guidance for future improvements in the physical forecast model and data assimilation methods.

However, detection and quantification of these trend errors can be non-trivial due to high sub-seasonal to interannual variability in combination with weak trends. We present methods to diagnose robustness and strength of observed trends and assess their correct representation by hindcast ensembles, using two examples:

1) Underestimation of Arctic warming trends in ECMWF sub-seasonal hindcasts
2) Overestimation of tropical Pacific warming trends in ECMWF seasonal hindcasts

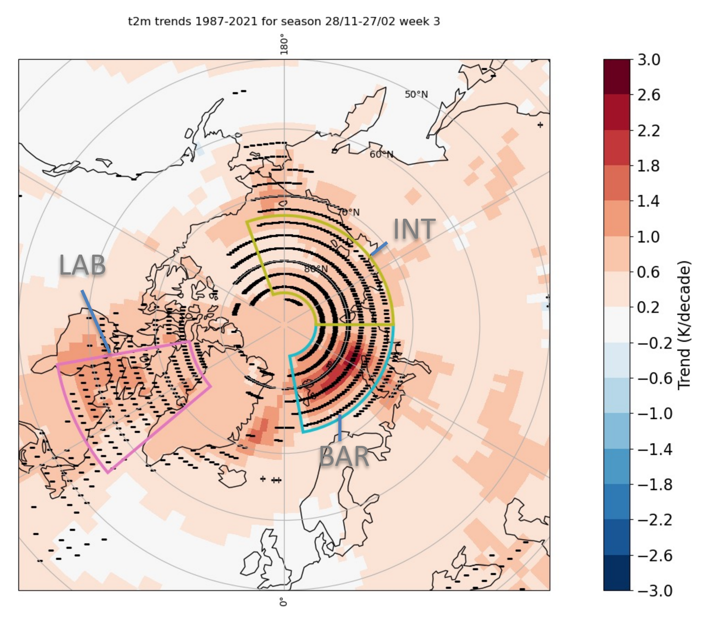
Underestimation of Arctic warming trends in ECMWF sub-seasonal hindcasts

***Fig 1**: ERA5 DJF trend from Dec 1986 to Feb 2022 for (a) 2m temperature, (b) sea ice concentration, (c) T850, (d) Z500*



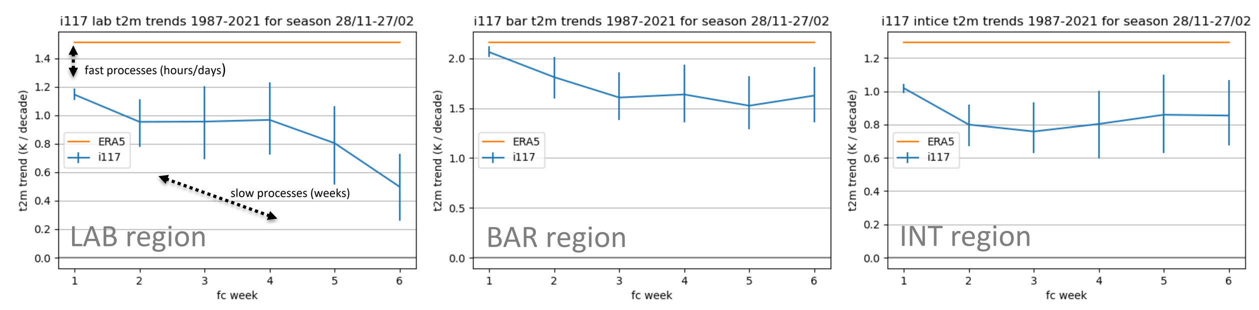
Robust and strong trend should pass the following three tests (stippling):
1. Non-zero seasonal trend (Wilcoxon signed-rank test on weekly trends)
2. Low sensitivity to leaving out single years (< 10%)
3. High fraction of total variance explained by trend (> 10%)

***Fig 2**: 48R1 DJF hindcast trend (week 3) from Dec 1986 to Feb 2022 for 2m temperature: contours show ensemble median, and -/+ stippling indicates significant under-/overestimation of ERA5 trend*



Hindcast ensemble is diagnosed to under-/overestimate the ERA5 trend if less/more than 2.5% of randomly drawn single-member trends are lower/higher than the ERA5 trend.

***Fig 3**: 1986-2022 DJF t2m trend in ERA5 (horizontal line) and in the hindcast ensemble (blue lines) over lead time and for different regions. Vertical error bars represent the central 95% of the distribution of single-member trends.*

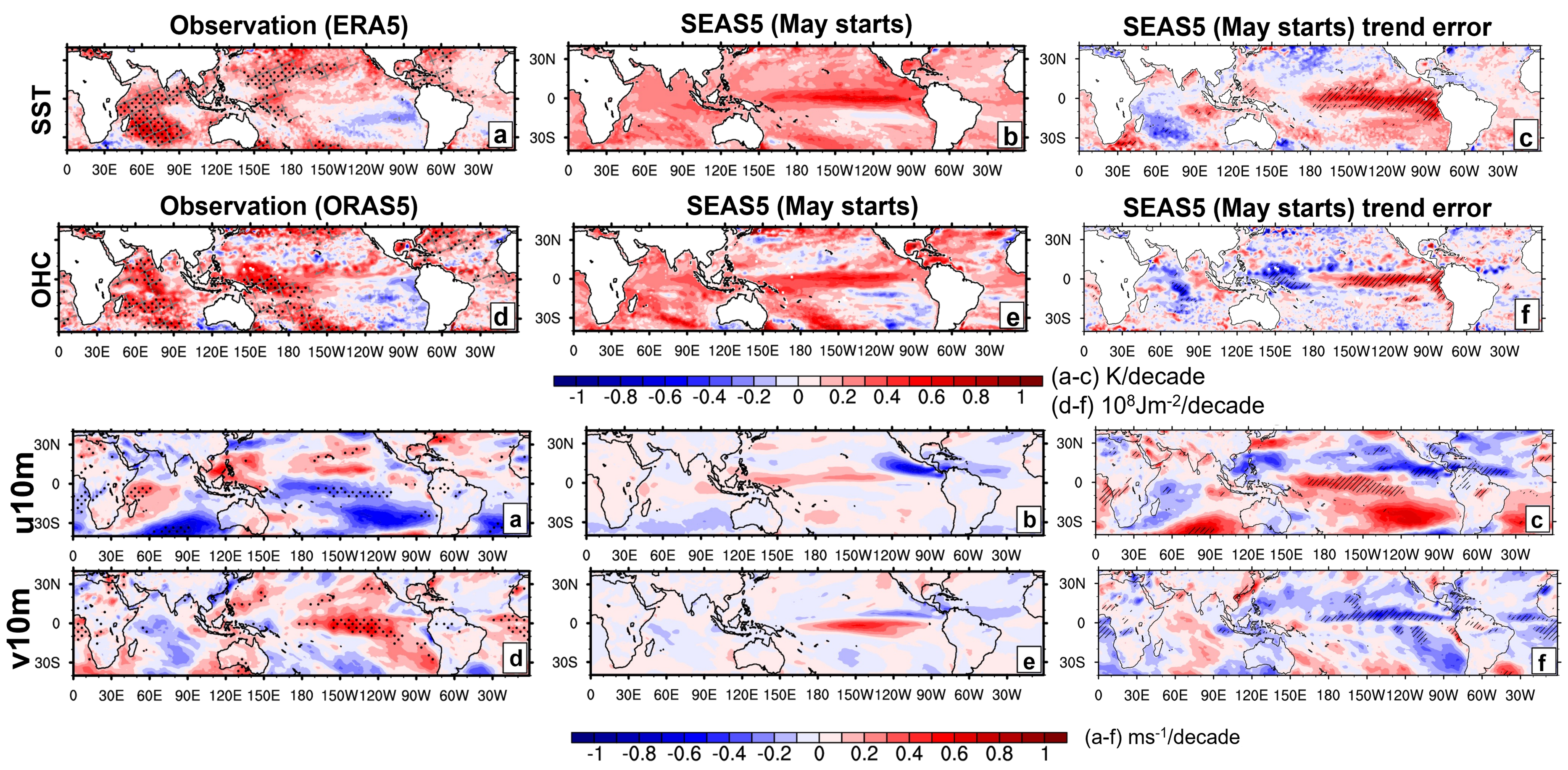


- ERA5 t2m trend underestimated by up to 50%, depending on lead time and region
- Underestimation in week 1 caused by misrepresentation of fast (local) processes, such as sea-ice thermodynamics (numerical experiments not shown here)
- Increasing underestimation for longer lead times caused by misrepresentation of slow (remote) processes such as NH circulation trends (numerical experiments not shown here)

S. Tietsche, M. Mayer, A. Weisheimer, F. Vitart, M. A. Balmaseda: Underestimation of winter Arctic warming trends in sub-seasonal hindcasts (in prep.)

Overestimation of tropical Pacific warming trends in ECMWF seasonal hindcasts

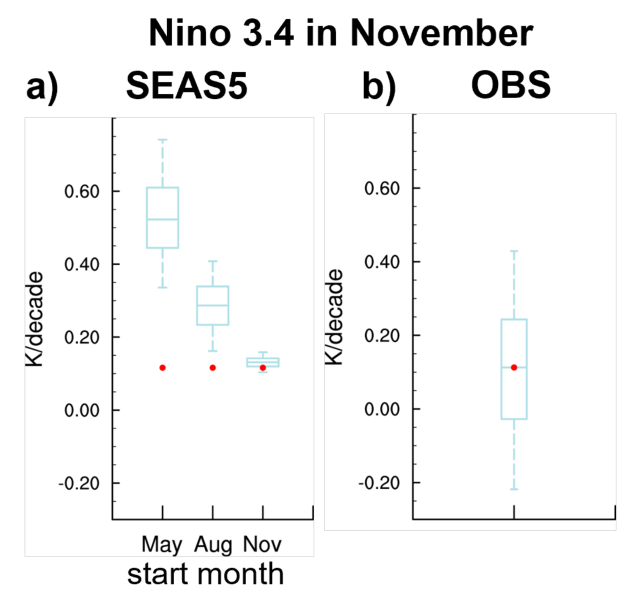
***Fig 4**: Reanalysis (ERA5/ORAS5) versus hindcast (SEAS5) trends for Nov 1993-2019, with markers indicated significance tests:*
- *Stippling (left column): trend is statistically significant (two-sided t-test)*
- *Grey hatching (left column): trends are robust to outliers and contribute > 10% to total variance*
- *Black hatching (right column): reanalysis trend outside 0.5th to 99.5th percentile of single-member hindcast trend*



Conclusions are drawn only where trends pass a series of significance tests (see above):
- ECMWF seasonal hindcasts underestimate cooling trend in south-eastern tropical Pacific
- Associated with underestimation of observed trend towards stronger equatorial easterlies and northward cross-equatorial wind in Pacific
- Trend errors also present in hindcasts with prescribed observed SST (not shown), indicating shortcomings of atmospheric model

***Fig 5**: Trends of November SST in Nino 3.4 region. The box plot in (a) shows the distribution of single-member trends in SEAS5 initialized in May, Aug and Nov.*

Dots show ERA5 trend, and box plot in (b) shows distribution of in-sample trends for a trend-free second-order autoregressive random process with parameters estimated from the ERA5 time series.



Distribution of hindcast trends for the same valid month are inconsistent with each other, and inconsistent with the reanalysis trend.

M. Mayer, M. A. Balmaseda, F. Vitart, S. Tietsche: Tropical Pacific trends in the ECMWF seasonal system and implications for predictions of the 2020-2022 triple-dip La Niña (submitted to J. Climate)

Summary of ECMWF hindcasts results

Arctic regions
- Winter surface warming trends over the Arctic regions of > 1 K / decade are *underestimated* by ECMWF sub-seasonal hindcasts
- Combination of fast processes (hours/days) and slow processes (weeks)

Tropical Pacific
- Overestimation of tropical Pacific SST trends in ECMWF seasonal forecasts, leading to El Niño false alarms in recent years and poor prediction of the triple-dip La Niña 2020-2022
- Associated with underestimation of wind-evaporation-SST feedback

General remarks on trend diagnostics

- Misrepresentation of climate trends in sub-seasonal and seasonal hindcasts affects forecast skill and points to deficiencies in the forecast model or the initialisation methods
- Dedicated trend diagnostics are needed, to assess robustness and strength of observed trends, and test their correct representation in s2s hindcasts
- With climate change now becoming evident in many regions and parameters over a typical hindcast period, s2s forecasting systems need improved fidelity in representing climate change