ECMWF road towards the extended range ensemble forecasting

Laura Ferranti

ECMWF Laura.Ferranti@ecmwf.int

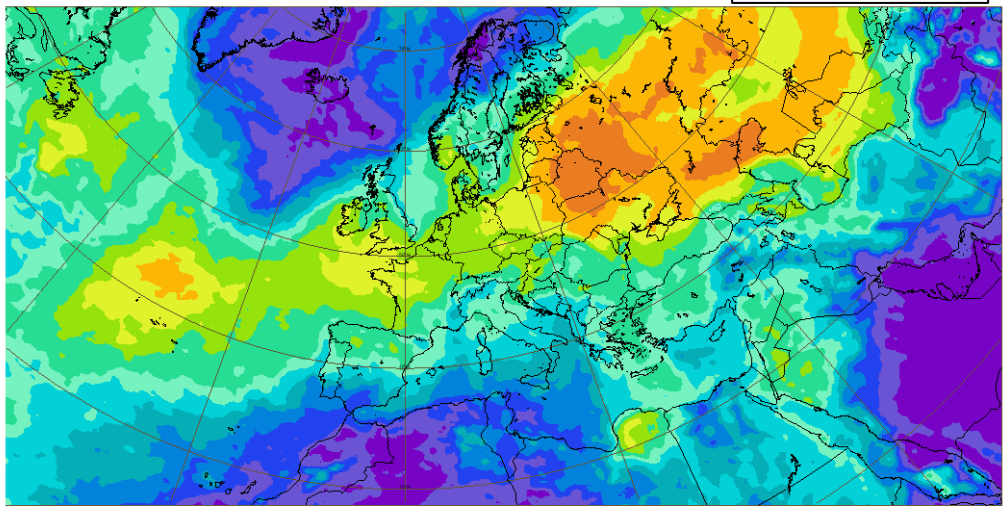
Thanks to M. Balmaseda, T. Stockdale, F. Vitart and A. Weisheimer

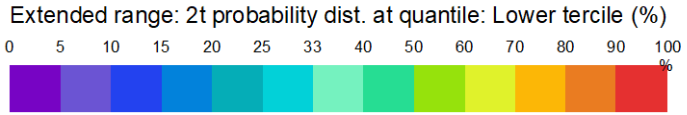
ECMWF

ECMWF produces **ensemble** forecasts for extended and seasonal ranges

Forecast Th24Nov 2022 valid :Mon5-Mon12Dec 2022
(+432) Prob for lower third of the climate distr.

Week 2.5

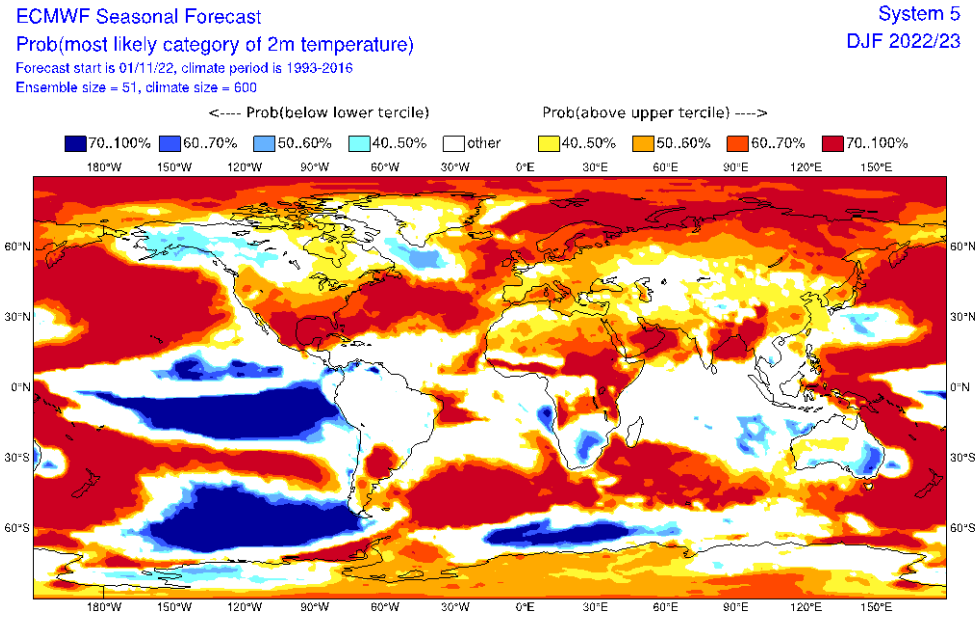


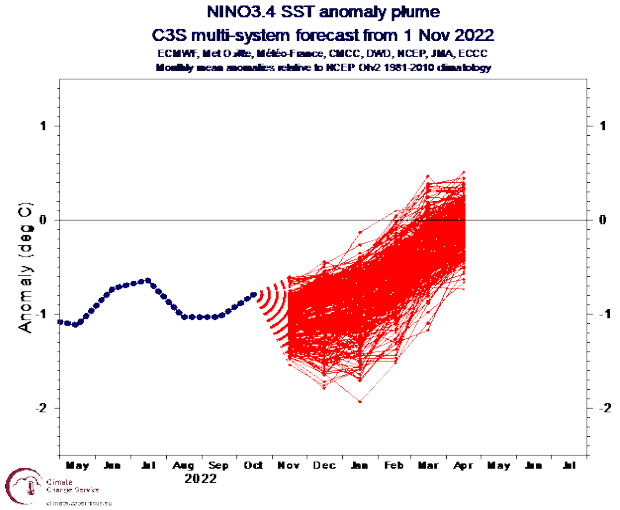


These ensemble predictions are averaged over a period (weeks, months) and provide probabilities of anomalous conditions (temperature/precipitation)

The skill of these prediction stem from the long-term variations associated with phenomena such as ENSO and MJO.

Uncertainties in the ocean become dominant .

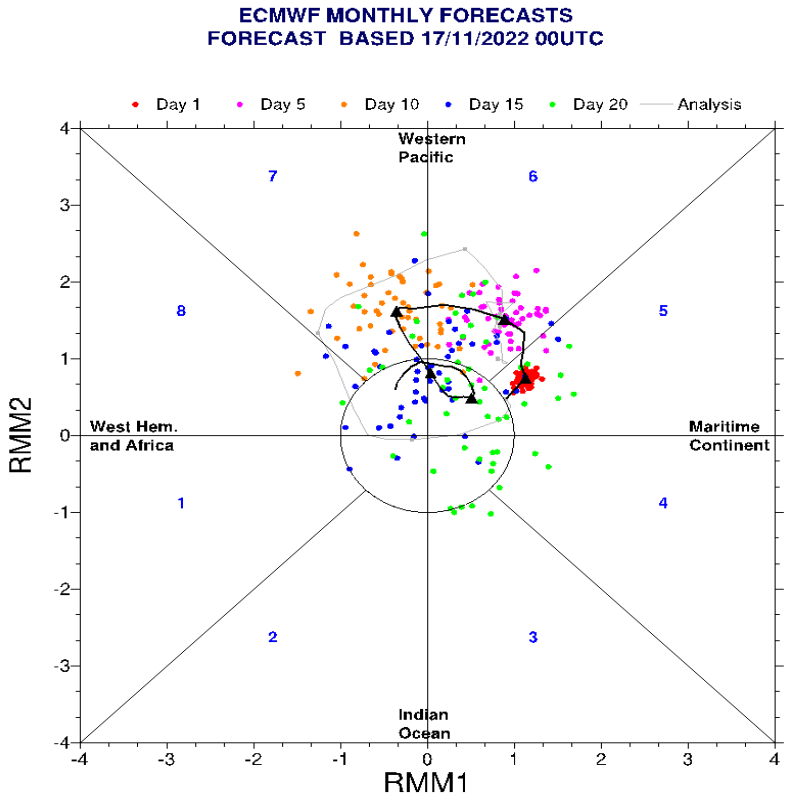


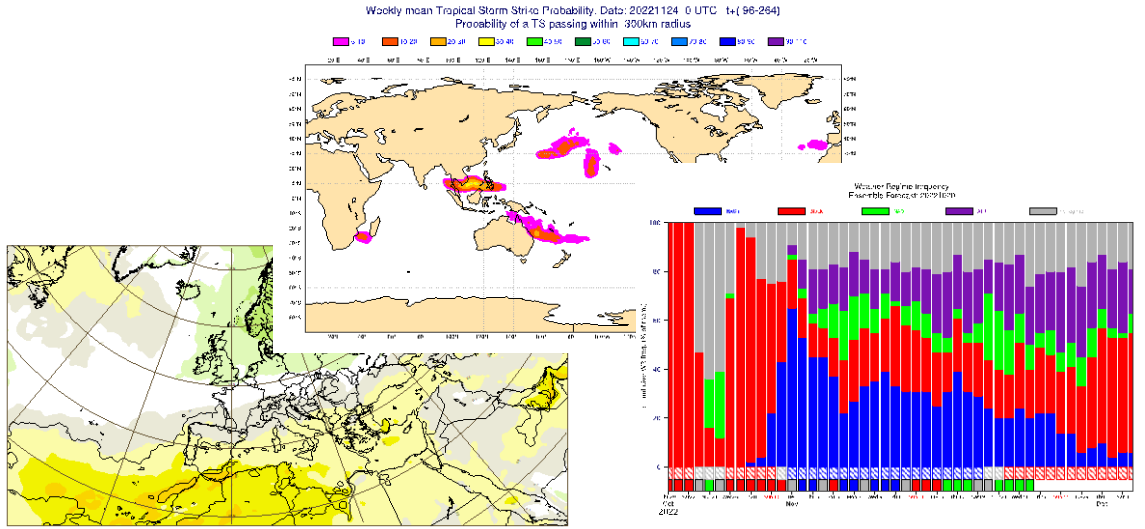


Multi-model C3S plumes
https://climate.copernicus.eu/charts/

The operational extended range ensemble prediction system:

2004	2008	2010	2011	2012	2015	2023
TL159 IFS+Hope 51m Issued weekly 32day 12 years/5m rfc	Tl399/Tl255 VAREPS 51m 18 years /5m rfc	T639/T319	IFS+NEMO 2- weekly	20 years rfc	Issued weekly 46day 2-weekly rfc -11m	Daily 101-members Fixed resol. T319



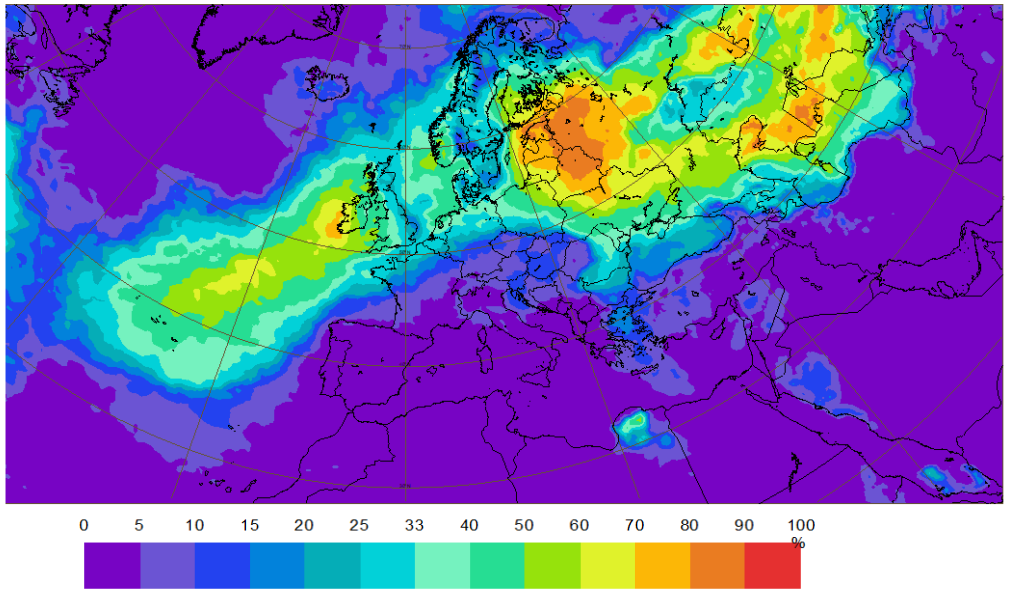


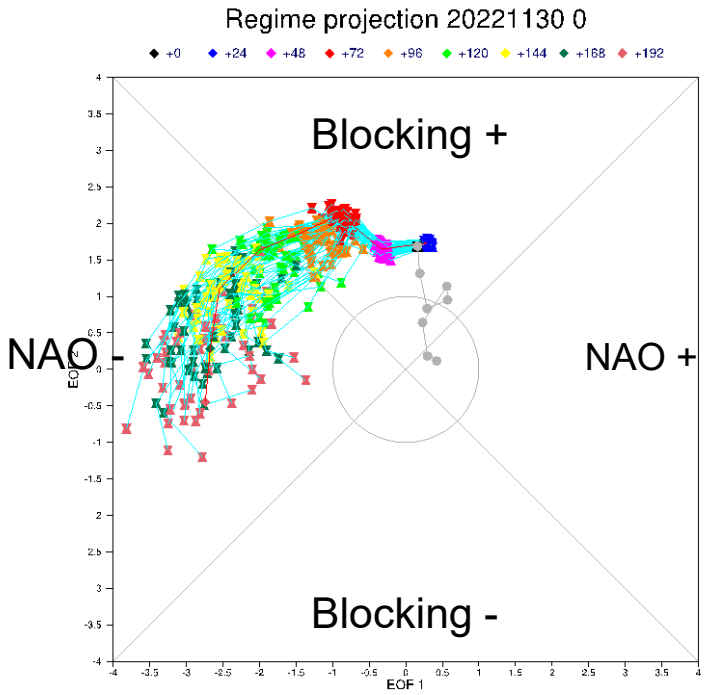
wide range of products

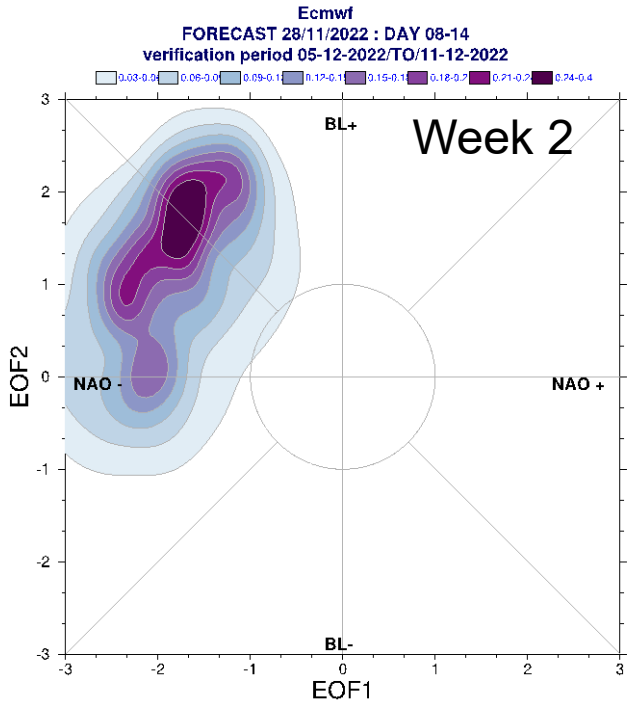
growing interest and demand to access these forecasts

Recent Forecasts: cold spell over Europe

Prob. for 2mt in lower 20% of climate
For. 28 Nov 2022 – valid time: 5-12 Dec 2022 Week 2

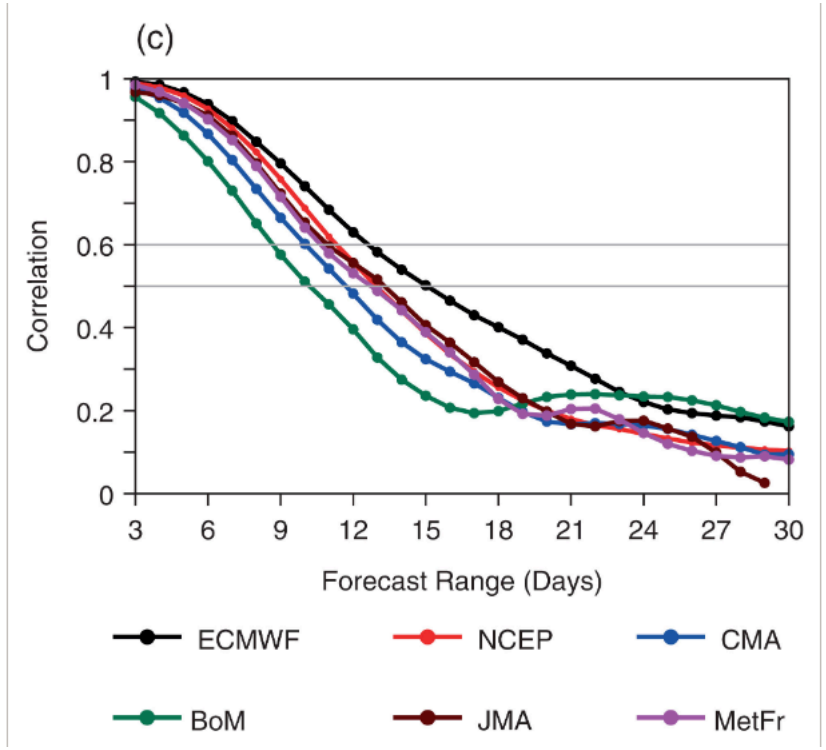


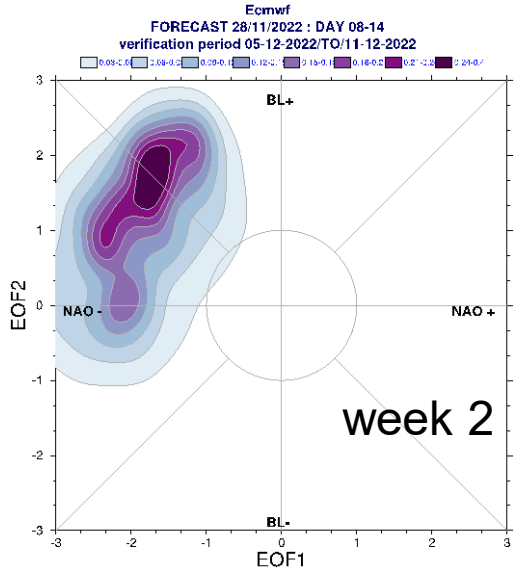


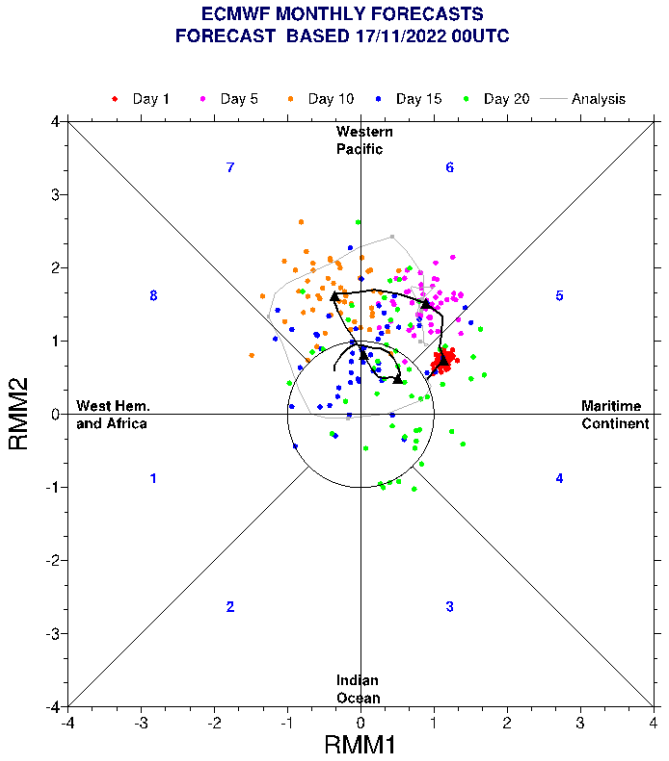


How accurate are likely to be such forecast ?

Bivariate correlation







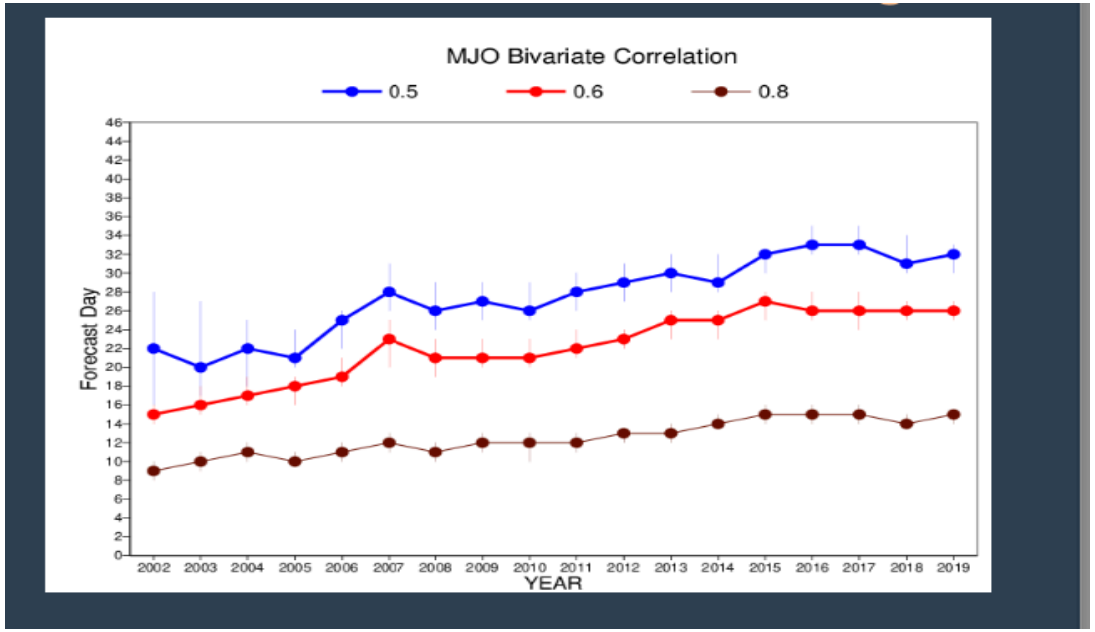
Useful skill beyond 2weeks

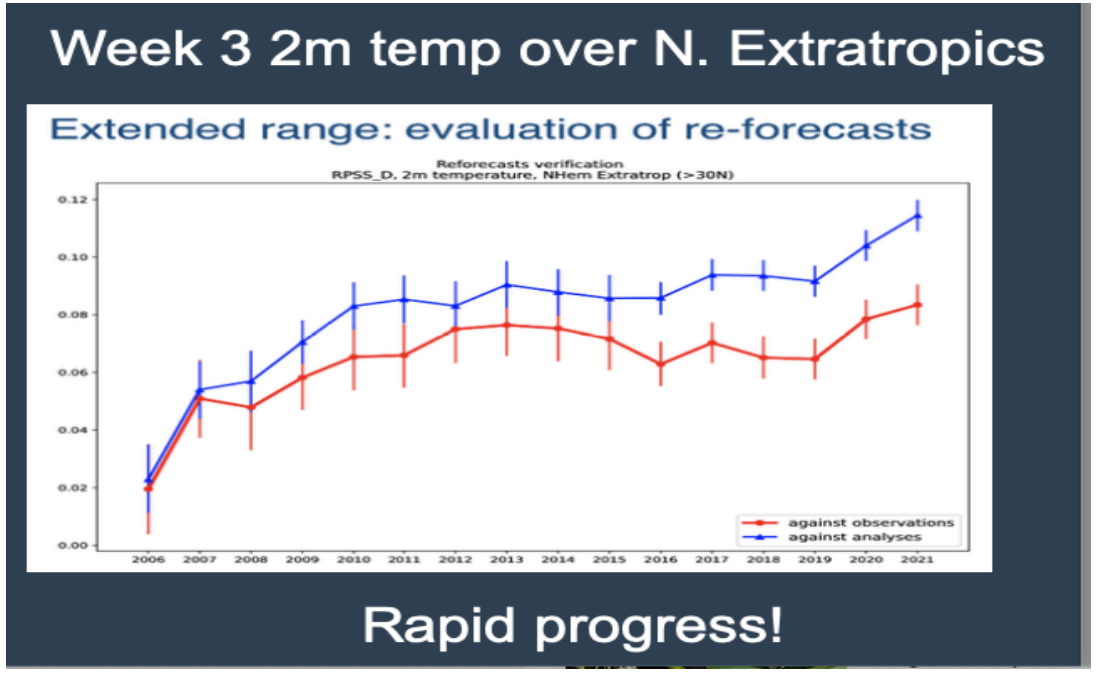
Ferranti et al 2019 QJRMS

The predictability of such events (BLO→NAO-) is enhanced by tropical–extratropical teleconnections resulting from MJO activity.

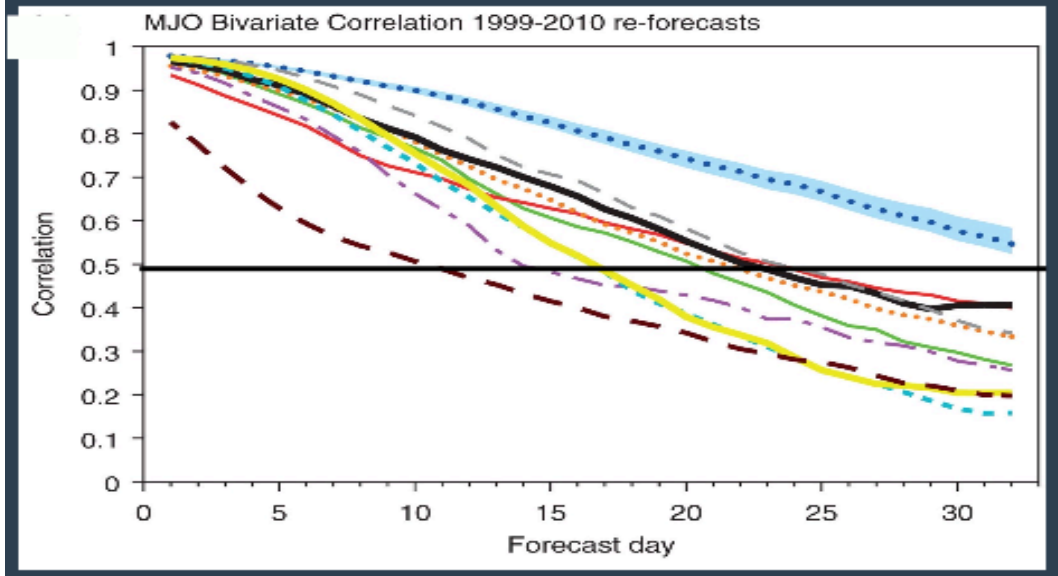
The extended range forecast skill is increasing

Skill evolution for the MJO predictions





MJO Skill in S2S database

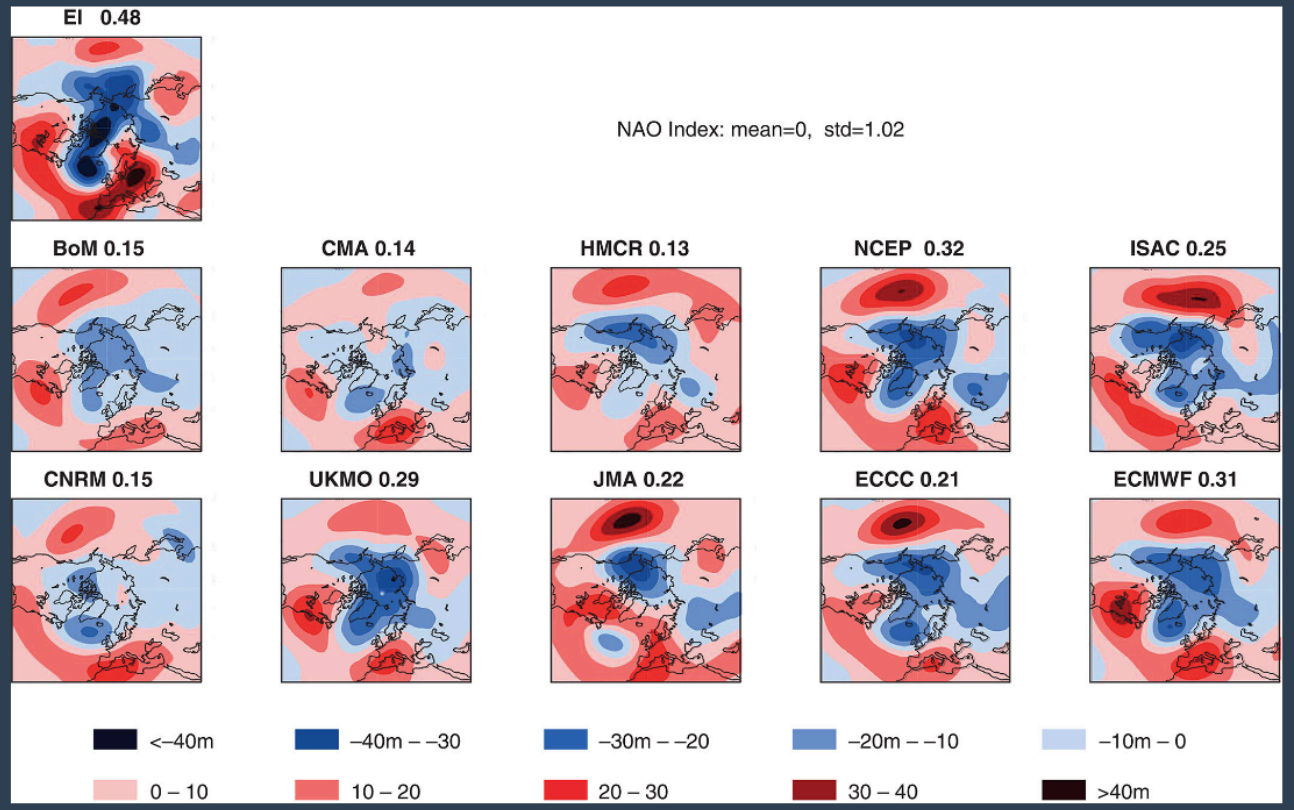


Vitart, 2017

The skill in predicting MJO evolution is about 4weeks ahead in S2S models

Impact of the MJO on the N. Extratropics

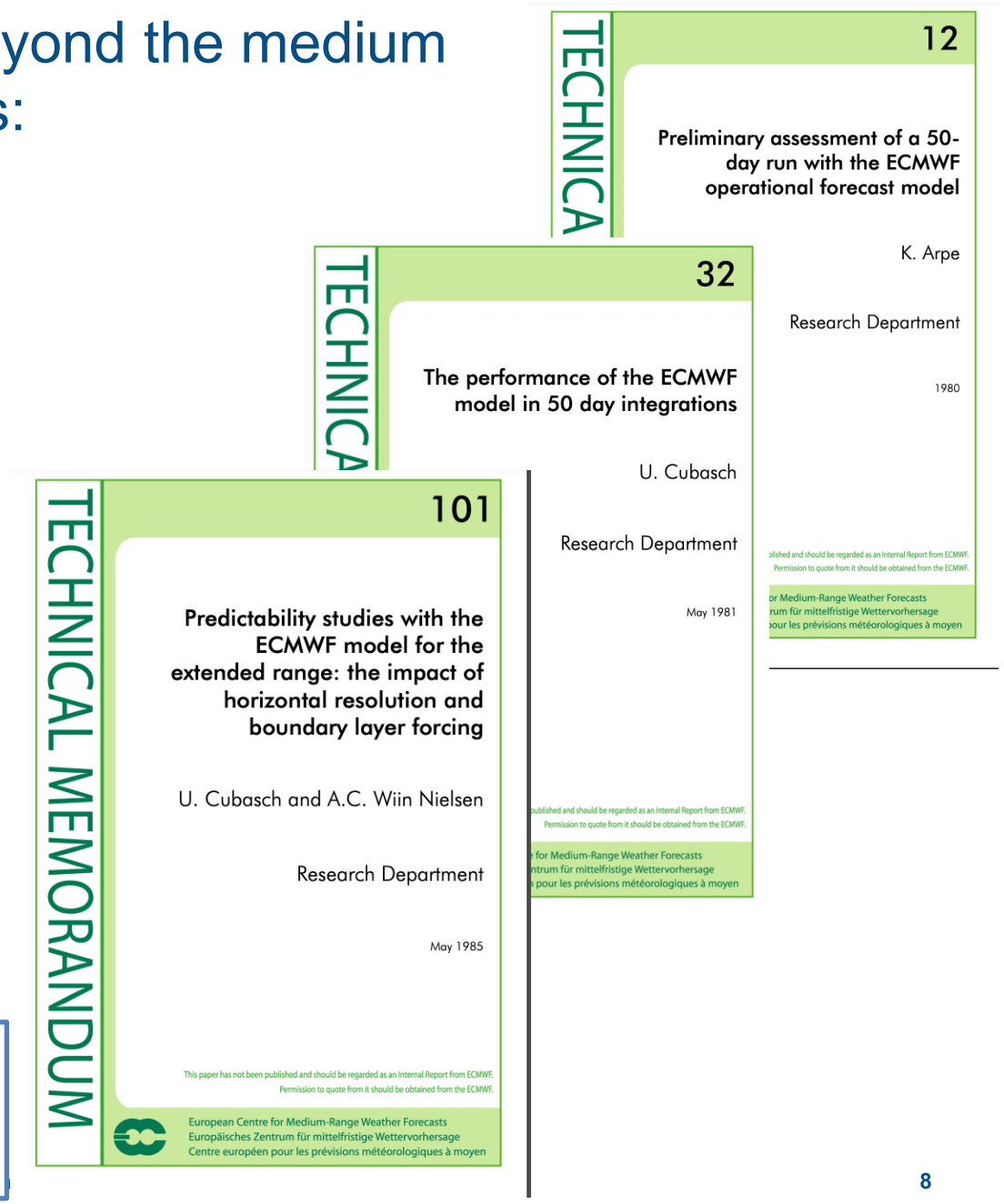
3 pentads after MJO in phase 3



S2S models simulate well the MJO teleconnection patterns but underestimate the amplitude of the MJO teleconnections.

At ECMWF research on predictability beyond the medium range started in the ’80s:

These early studies aimed to evaluate the mean bias sensitivity to model formulation and horizontal resolution and boundary forcing



The research plan approved by ECMWF Council 1986: “ Extended range integrations will be needed to study systematic error and atmospheric predictability”

Diagnostic and predictability section (September 1987) :

Diagnostic of model performance, assessment of model climate statistics - (mean biases and variability) - analysis of AMIP integrations

Evaluation of predictability beyond the medium range using time-lagged ensembles of 120days simulations forced by obs. SST and run simulations with idealized SST anomalies.

C. Branković, F. Molteni, E. Klinker, T. Palmer, S. Tibaldi, L. Ferranti

Tropical-extratropical interaction associated with the MJO and its impact on the forecast skill

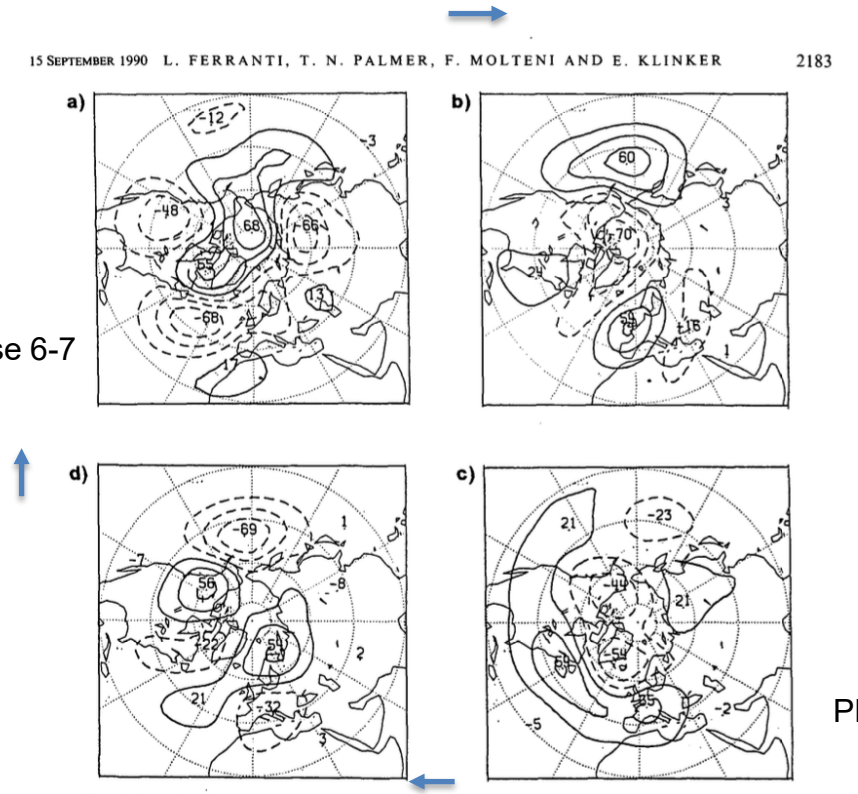


FIG. 5. Composite of extratropical 500 mb geopotential height formed by selecting days when a) the coefficient of the second EOF of OLR was greater than one standard deviation, b) the coefficient of the first EOF of OLR was greater than one standard deviation, c) the coefficient of the second EOF of OLR was less than minus one standard deviation, d) the coefficient of the first EOF of OLR was less than minus one standard deviation. Contour interval 20 m.

Phase 6-7

Phase 2-3

— Control
…. Rel. verifying analysis
- - - Rel. initial analysis

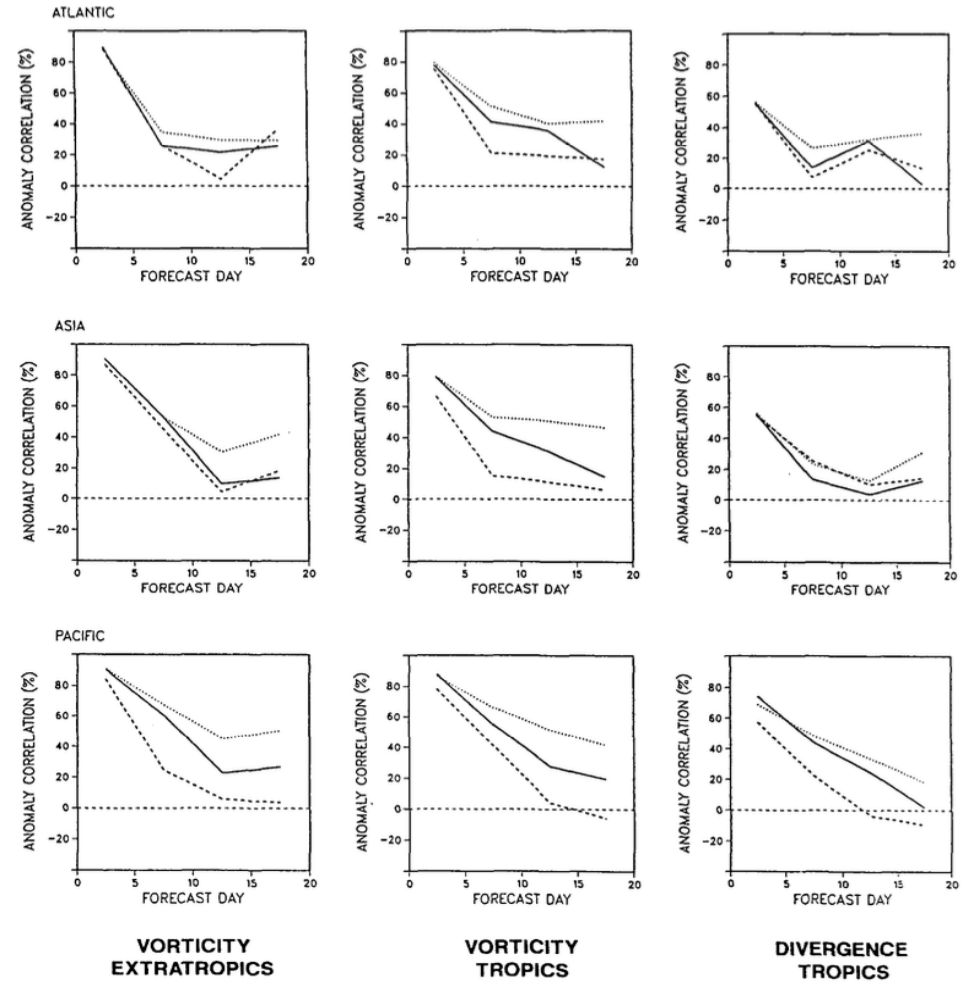


FIG. 16. Anomaly correlation coefficient of 5-day mean 200 mb vorticity and divergence fields, averaged over all four experiments. Left hand column: extratropical vorticity scores; middle column: tropical vorticity scores; right hand column: tropical divergence scores. Scores for the control forecasts are shown as solid lines; scores for the experiments with relaxation towards the verifying analysis are shown as dotted lines; scores for the experiments with relaxation towards initial conditions are shown as dashed lines.

Beyond medium range the impact of tropics on the extra-tropics is important particularly during period when the MJO is active

Ferranti et al. 1990: J. Atmos .Sc.

Seasonal forecasting experimentation is included in the ECMWF activity:

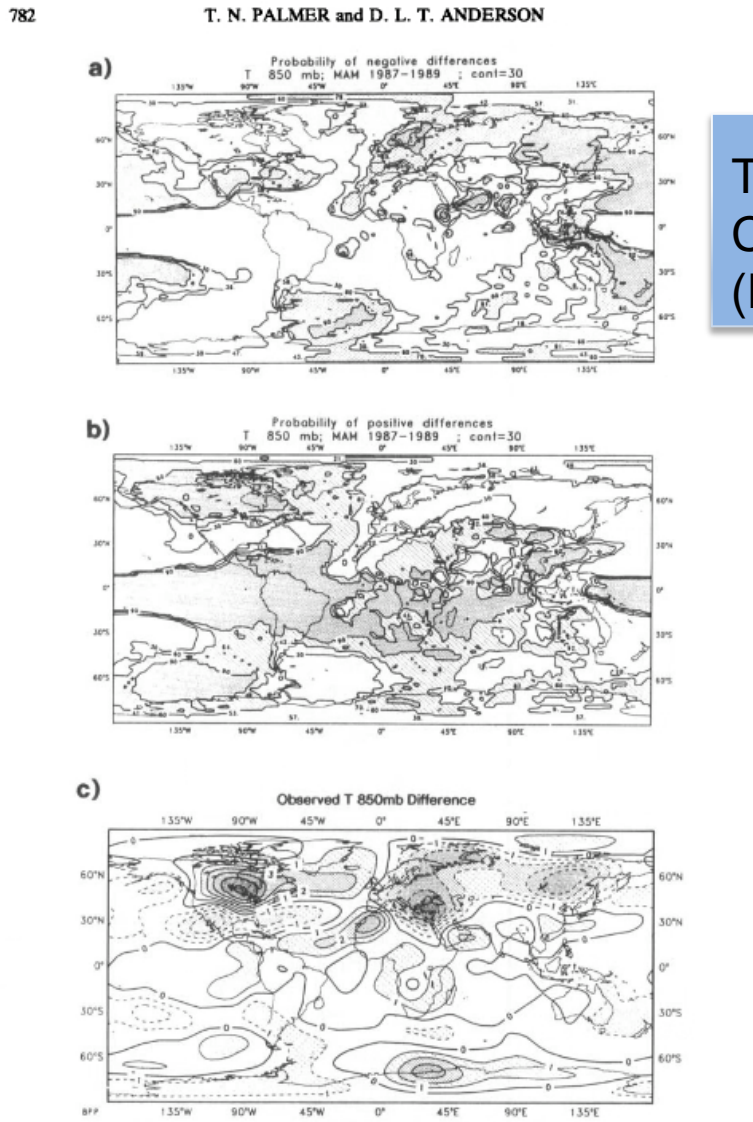
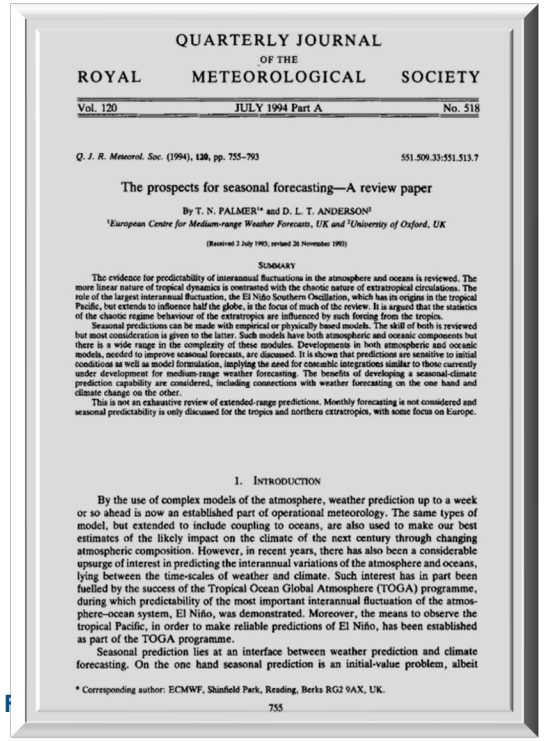


Figure 15. Probability estimates of 850 mb temperature difference over Europe based on nine-member ensembles of 120-day integrations with observed SST. March, April, May (MAM) 1987–MAM 1989. Probability (%) that temperature difference is (a) negative and (b) positive; (c) is the verification. Contours for (a) and (b)—30%, 60%, 90%.

The review paper by Palmer and Anderson (*1994 in QJRMS*) lead to the Council's decision to approve the development of seasonal predictions (December 1994)



QUARTERLY JOURNAL
OF THE
ROYAL METEOROLOGICAL SOCIETY

Vol. 120 JULY 1994 Part A No. 518

Q. J. R. Meteorol. Soc. (1994), **120**, pp. 755–793 551.509.33:551.513.7

The prospects for seasonal forecasting—A review paper

By T. N. PALMER[1]* and D. L. T. ANDERSON[2]

[1]*European Centre for Medium-range Weather Forecasts, UK and* [2]*University of Oxford, UK*

(Received 2 July 1993; revised 26 November 1993)

SUMMARY

The evidence for predictability of interannual fluctuations in the atmosphere and oceans is reviewed. The more linear nature of tropical dynamics is contrasted with the chaotic nature of extratropical circulations. The role of the largest interannual fluctuation, the El Niño Southern Oscillation, which has its origins in the tropical Pacific, but extends to influence half the globe, is the focus of much of the review. It is argued that the statistics of the chaotic regime behaviour of the extratropics are influenced by such forcing from the tropics.

Seasonal predictions can be made with empirical or physically based models. The skill of both is reviewed but most consideration is given to the latter. Such models have both atmospheric and oceanic components but there is a wide range in the complexity of these modules. Developments in both atmospheric and oceanic models, needed to improve seasonal forecasts, are discussed. It is shown that predictions are sensitive to initial conditions as well as model formulation, implying the need for ensemble integrations similar to those currently under development for medium-range weather forecasting. The benefits of developing a seasonal-climate prediction capability are considered, including connections with weather forecasting on the one hand and climate change on the other.

This is not an exhaustive review of extended-range predictions. Monthly forecasting is not considered and seasonal predictability is only discussed for the tropics and northern extratropics, with some focus on Europe.

1. INTRODUCTION

By the use of complex models of the atmosphere, weather prediction up to a week or so ahead is now an established part of operational meteorology. The same types of model, but extended to include coupling to oceans, are also used to make our best estimates of the likely impact on the climate of the next century through changing atmospheric composition. However, in recent years, there has also been a considerable upsurge of interest in predicting the interannual variations of the atmosphere and oceans, lying between the time-scales of weather and climate. Such interest has in part been fuelled by the success of the Tropical Ocean Global Atmosphere (TOGA) programme, during which predictability of the most important interannual fluctuation of the atmosphere–ocean system, El Niño, was demonstrated. Moreover, the means to observe the tropical Pacific, in order to make reliable predictions of El Niño, has been established as part of the TOGA programme.

Seasonal prediction lies at an interface between weather prediction and climate forecasting. On the one hand seasonal prediction is an initial-value problem, albeit

* Corresponding author: ECMWF, Shinfield Park, Reading, Berks RG2 9AX, UK.

755

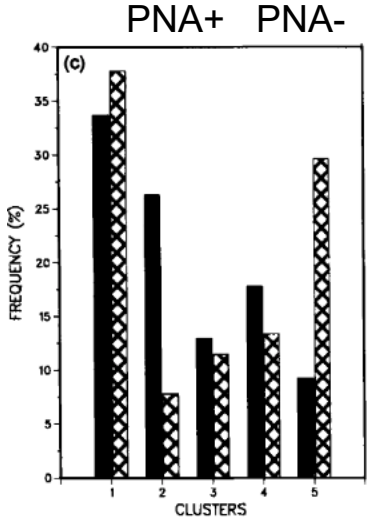


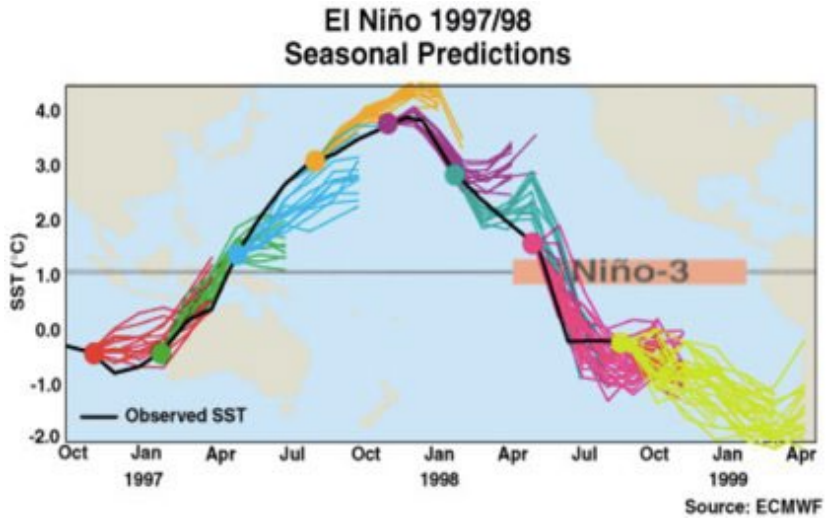
Fig. 16c) Freq. of clusters from simulated 5-day mean (solid) DJF1986/87 (hatched) DJF1988/89

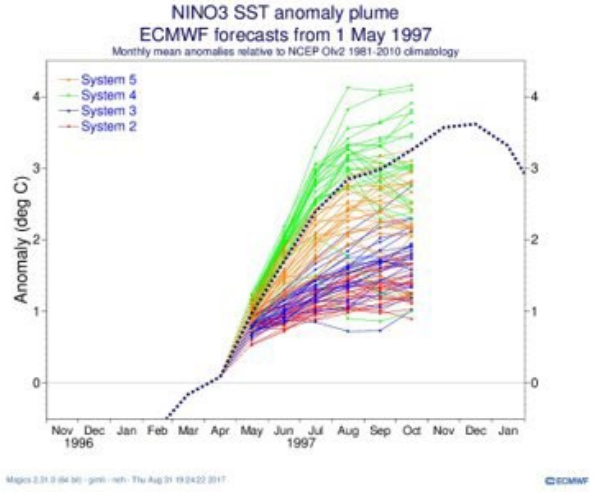
Seasonal forecasting: rapid progress

PROVOST (1995-1998). (European proj. Predictions of Climate Variations on Seasonal to interannual timescales)

Development of the first real-time seasonal forecast system - successful prediction of El Nino 1997/1998 and La Nina 1998/1999 *(Stockdale et al. Nature 1998)*

The Seasonal ensemble forecasting system became operational in 2000





European projects: DEMETER and ENSEMBLES

Development of a **E**uropean **M**ultimodel **E**nsemble system for seasonal to in**TER**annual prediction (**DEMETER**) (2000-2003) developed of well validated coupled multi-model ensemble system for seasonal predictions

Multi-model combinations are more skilful than single models and the benefit is not just associated with a larger ensemble - DEMETER data was used to run crop yield and malaria predictions model, establishing practical utility in different sectors - Data availability to promote further studies and training

The award was made in recognition of their paper entitled “Development of a European Multimodel Ensemble System for Seasonal-to-Interannual Prediction (DEMETER)” *BAMS*, 2004

EUROSIP first operational multi-model system (2005-2019) - a legacy from DEMETER – 3 European coupled systems, real-time digital and graphical products

ENSEMBLES (2004-2009) focus on the development of predictions of climate from season to decades. Produce climate information and the associated uncertainties - probabilistic climate predictions for Europe

DEMETER awarded the Norbert Gerbier Mumm International Award

Prof. A.P Morse, Dr Renate Hagedorn (Director Weather forecasting services at DWD) and Dr Francisco Doblas-Reyes (Director of Earth Sciences at BSC). June 2006

Conclusions:

At ECMWF, the research on ensembles and predictability done in the ’90 provided the foundations of seasonal and extended range ensemble forecasting.

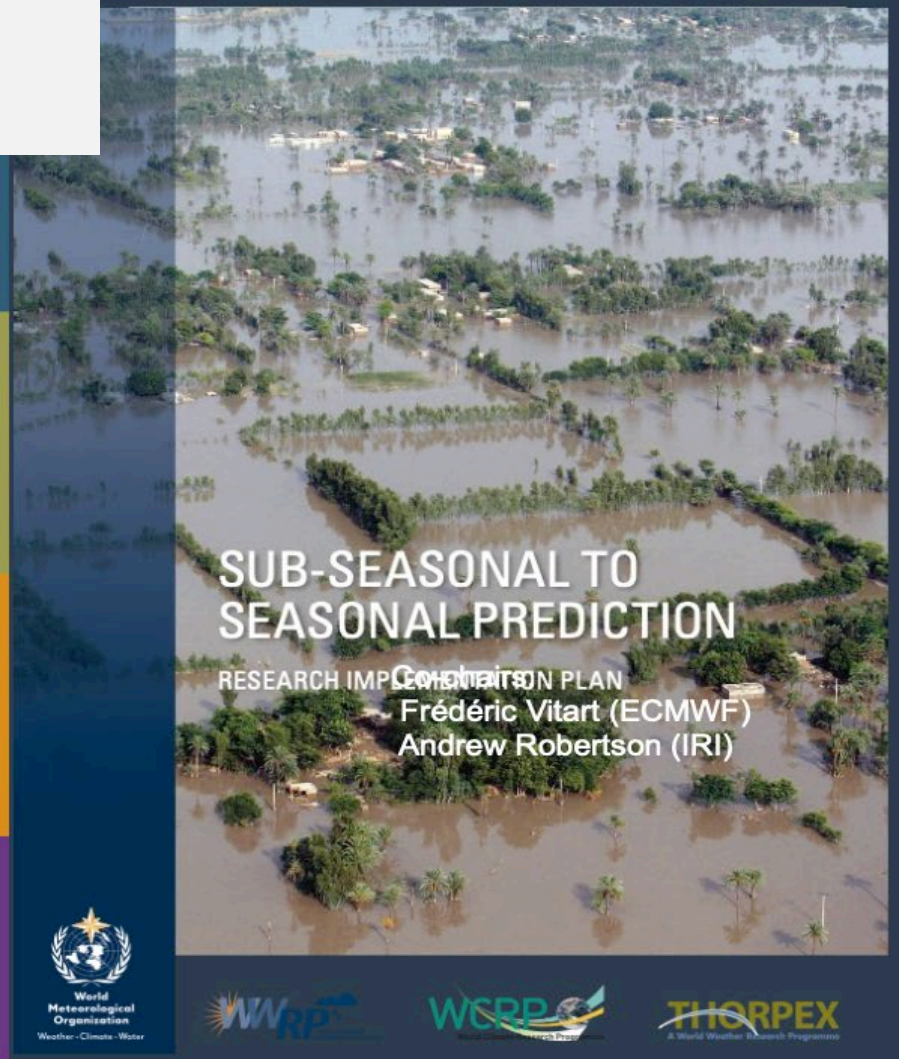
The development of an initialized dynamical ocean model coupled with the IFS, so essential for seasonal predictions, can be seen as an important step towards the current "Earth System modelling and data assimilation" at ECMWF.

Extended and seasonal ensembles are necessary components for the provision of a seamless probabilistic prediction of weather to climate which is so much in demand for humanitarian disaster risk management, commercial applications and for NMHs use. For this reason, it would be desirable to consider these forecast ranges as an integral part of the ECMWF ”core” activity.

Tim played a crucial role in paving the road to the current ECMWF capability in providing high quality probabilistic forecast from weather to climate.

The S2S project has provided a substantial contribution

The WWRP/WCRP S2S project 2013-2023

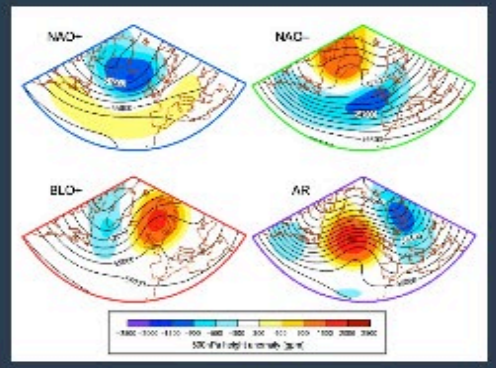


- Improve forecast skill and understanding on the sub-seasonal to seasonal timescale with special emphasis on high-impact weather events
- Promote the initiative's uptake by operational centres and exploitation by the applications community
- Capitalize on the expertise of the weather and climate research communities to address issues of importance to the Global Frame- work for Climate Services

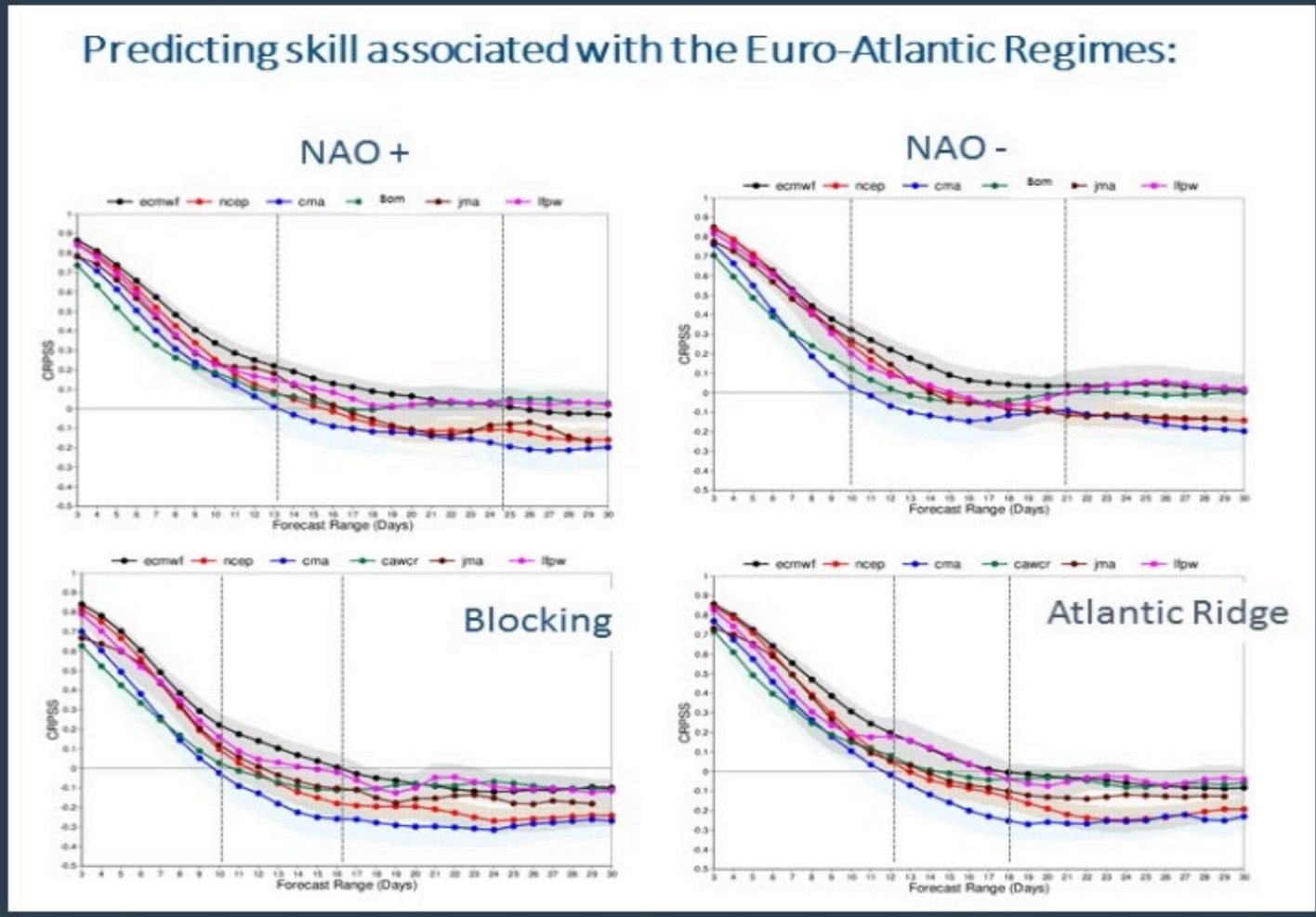
- *The S2S project started 2013 and is now in its second phase (2019-2023)*
- *International Coordination Office hosted by APCC.*
- *Contribution to S2S trust fund from Australia, Canada, UK and Germany.*

The project focuses on the forecast range between 2 weeks and a season.

Predicting skill associated with the Euro-Atlantic Regimes



- NAO+ and NAO- are more predictable than Blockings and Atlantic Ridge.
- The predictability of NAO is about 3 weeks
- Predictability of Blockings and Atlantic Ridge is about 2 weeks.



Ferranti et al, 2018

Extended range predictions with time lagged ensemble

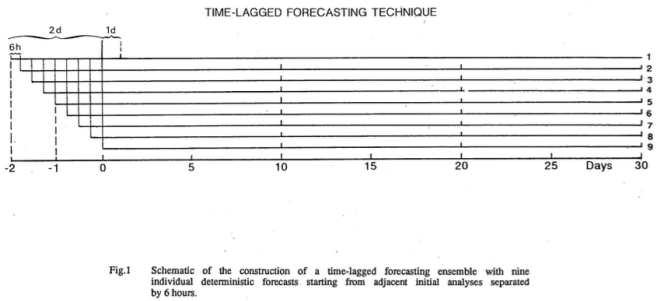


Fig.1 Schematic of the construction of a time-lagged forecasting ensemble with nine individual deterministic forecasts starting from adjacent initial analyses separated by 6 hours.

16 ensembles of time lagged forecast up to 30 days with realistic SST - Ensemble of 9members started from consecutive 6h analysis (*Brankovic et al 1990 QJRMS part.3*)

The ens. mean was consistently more skillful than its control at day 11-20.

By investigating the reason for the failure of a specific ensemble (for Jan 1986) they showed the skill sensitivity to model formulation suggesting that " *a methodology for Monte Carlo forecasting should include perturbations to model formulation as well as perturbations to initial conditions.*"

They also showed that the large-scale systematic errors in the tropics was a hindrance in assessing the extended range predictability.

They concluded by saying:
" *Given the results ….. we believe that prediction beyond the medium range is not currently viable. However, when forecast systematic error, particularly in the tropics, is reduced and when techniques that can identify the most rapidly growing pert. have been fully developed, then ….. probabilistic forecasting of time-mean weather may be feasible up to 2-3 weeks ahead.*"

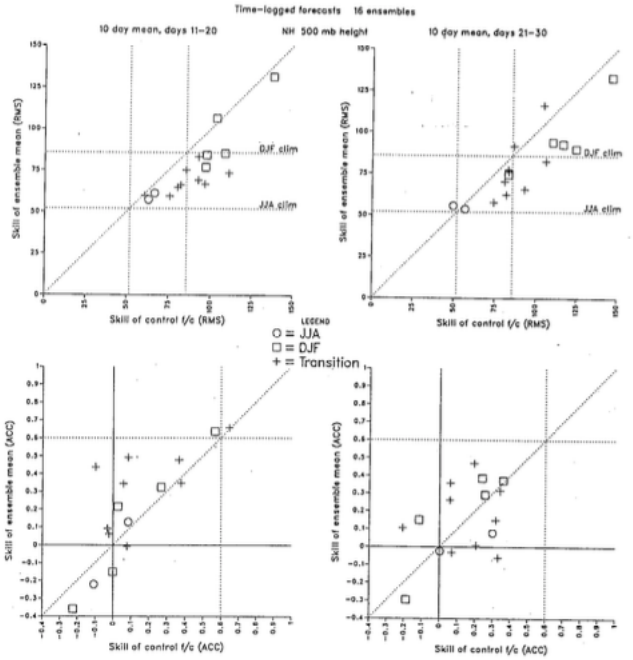


Fig.6 Scatter diagram of RMS error (top) and anomaly correlation coefficient (middle) of the northern hemisphere 500 mb heights, and anomaly correlation coefficient of the northern hemisphere 850 mb temperature (bottom) for ensemble-mean forecast vs. control forecast. Left hand column: days 11-20. Right hand column: days 21-30. RMS error in metres.