Seasonal forecasting: models, reanalyses, forcings

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Team members over the last 30 years:
David Anderson, Magdalena Balmaseda, Oscar Alves, Tim Palmer, Cedo Brancovic, Laura Ferranti, Frederic Vitart, Jerome Vialard, Jochen Segschneider, Arthur Vidard, Paco Doblas-Reyes, Renate Hagedorn, Alberto Troccoli, Antje Weisheimer, Kristian Mogensen, Franco Molteni, Linus Magnusson, Retish Senan, Hao Zuo, Stephanie Johnson, Edu Penabad, Anca Brookshaw, Dan Befort, Michael Meyer, ...

And support from many other colleagues in RD and FSD

ECMWF

A two-part presentation

- Where have we got to?
  - Brief history of seasonal prediction at ECMWF
  - Latest progress: Introducing SEAS6

- Where might we be going?
  - The limiting factors we presently face
    - Models
    - Reanalyses and sampling
    - Forcings

Seasonal forecasting – official project started in 1995

Forecasts issued from December 1997 onwards

T63L31/2°
208 km

ECMWF's Seasonal Forecast Project

HOME PAGE

ECMWF started an experimental programme in seasonal prediction in 1995.

This programme has not reached an operational status.

Nonetheless, taking into account the exceptional El Nino event of 1997, and following overarching WMO requirements, the ECMWF Council has decided to make a range of products from the experimental programme of seasonal prediction available on this site.

Any user of the seasonal forecasting products contained within this server (www.ecmwf.int) accepts all responsibility for the use. In particular, no claims of accuracy or precision of the forecasts will be made by the user which is inappropriate to their scientific basis.

Feedback from users on their experience with the products would be welcomed by ECMWF.

The products are available on an ongoing basis at the present time.

- INTRODUCTION
- PRODUCTS

Return to ECMWF home page

Please mail comments or questions to seasonal@ecmwf.int

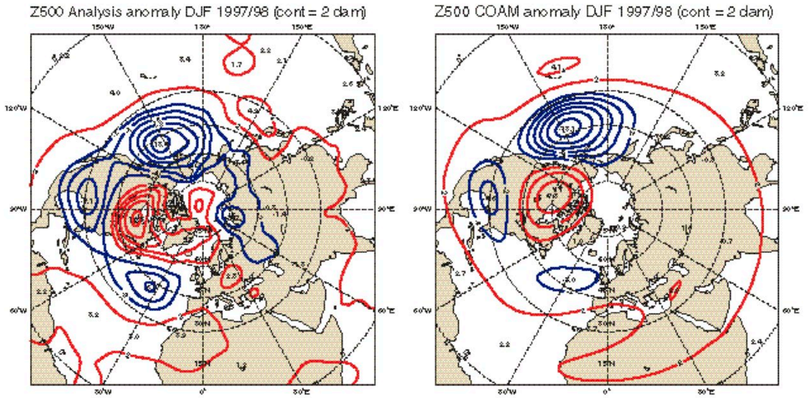

Figure 5: The anomalous height of the 500 hPa surface for DJF 97/98 from the coupled model prediction from October 1997 (right) and the verifying ECMWF analysis (left).

METEOROLOGICAL *ECMWF Newsletter Number 77 - Autumn 1997*

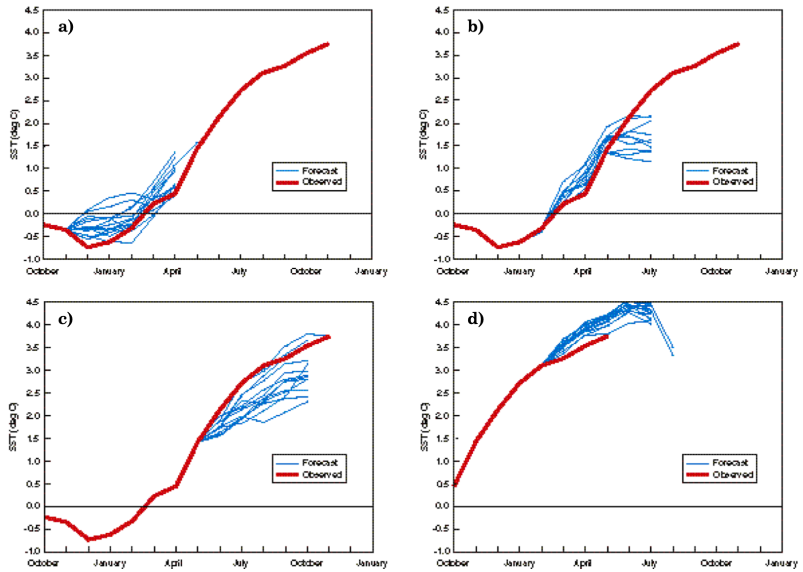

Fig 3: Plume of monthly mean SST anomalies predicted for the Nino3 region for forecasts initiated in a) November 96, b) February 97, c) May 97 and d) August 97. Three forecasts are initiated weekly and run for six months. The heavy line shows the observed values.

a)

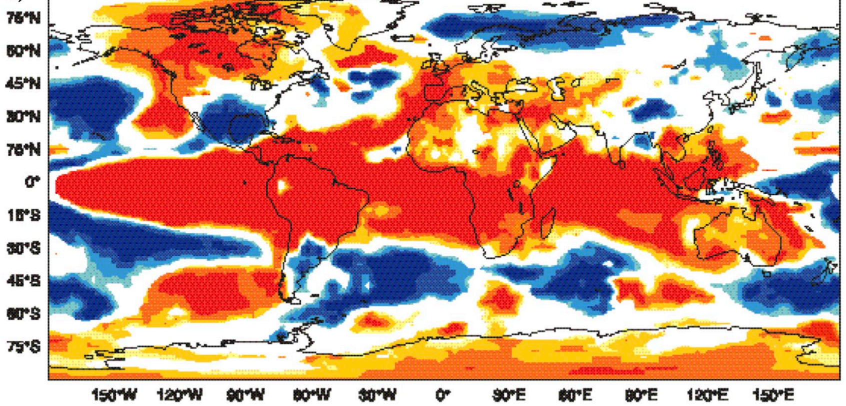

***Figure 3:** Probability forecasts of:*

a) 2 m temperature for the winter of 1997/8 for forecasts initiated in October '97. Deep red colours indicate high probability of above average temperature. Deep blue colours indicate high probability of below average temperatures.

b) Observed temperature anomalies represented as percentiles. (Reproduced

System 2 introduced in 2002

```
retrieve,
   stream=seas, system=2, method=1, number=0/to/39,
   class=od, expver=1, date=20030401, time=0,
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retrieve,
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ECMWF Newsletter No. 98 – Summer 2003 **METEOROLOGICAL**

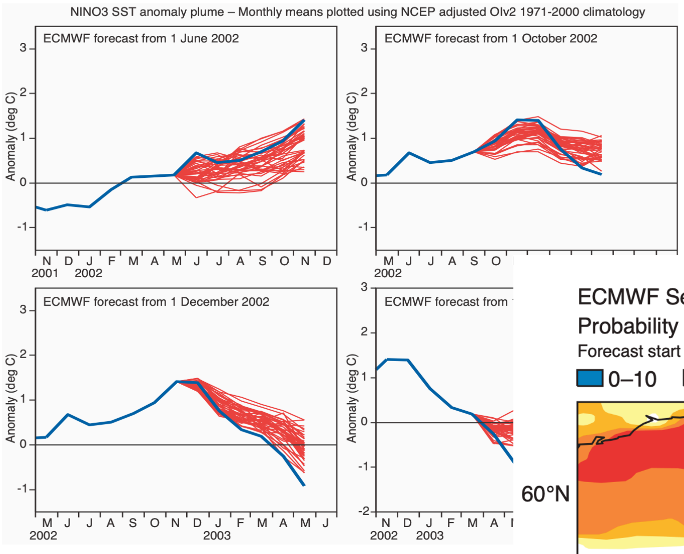


Figure 8 Plot of forecasts of Niño-3.4 at four start dates June, October, Decem
ensemble members. The heavy blue line represent
ıot shown) and December 2002 were especially goo
edicted range.

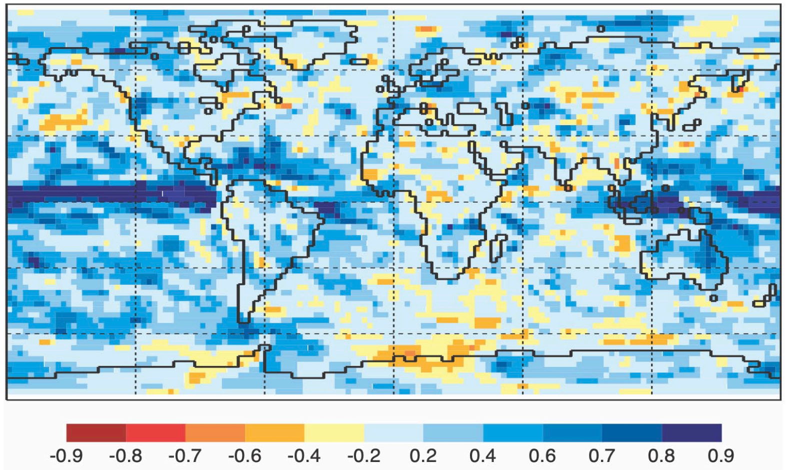
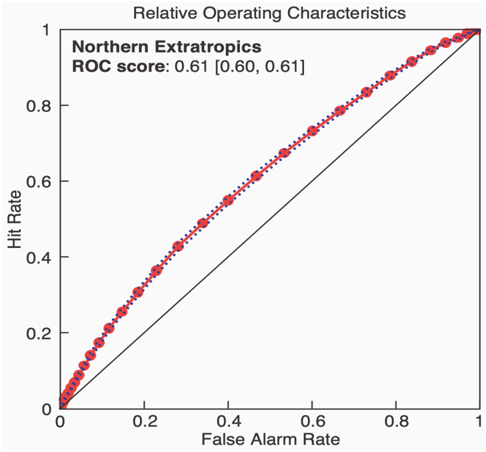
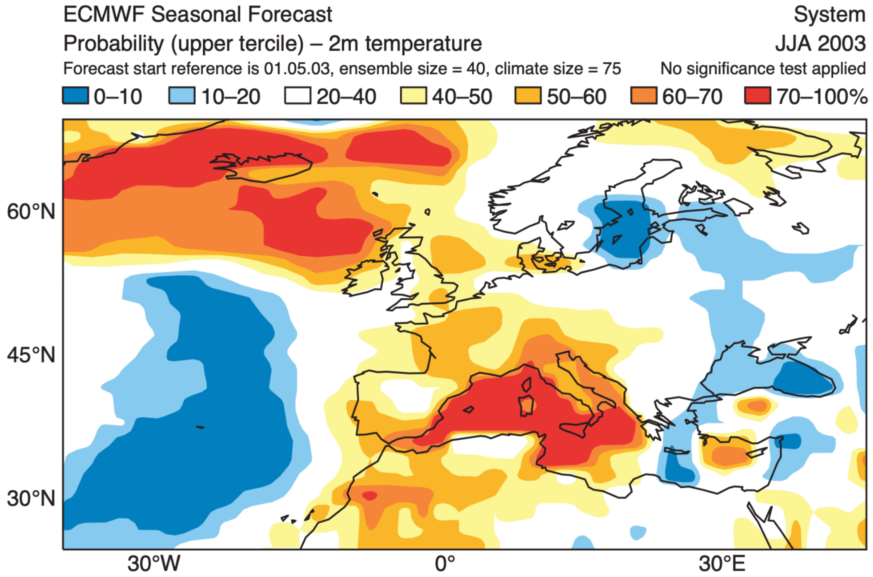


Figure 10 Map of temporal anomaly correlation of precipitation for June–July–August forecasts starting in May for the period 1987-2001.





$T_L95L40/1°$
208 km

System 2 introduced:

- Operational MARS archive, including reforecasts
- Verification plots
- Operational dissemination

System 3 introduced in 2007

- Ocean reanalysis from 1959
- Ocean data in MARS (HOPE ocean model, grib1)
- New MARS multi-model MMSF stream
- New web products

$T_L159L62/1°$
125 km

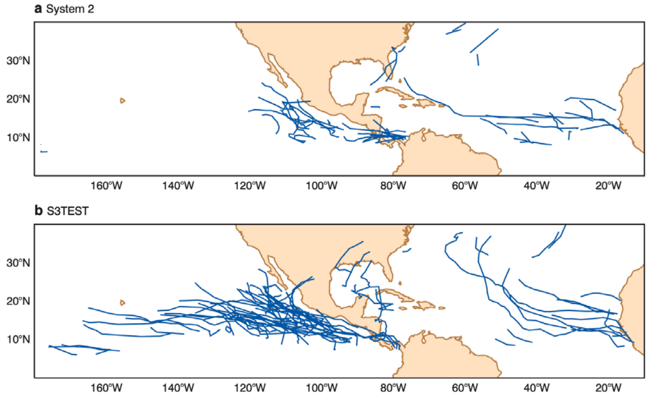


Figure 6 Model tropical storm tracks in the Atlantic and Eastern North Pacific for (a) System 2 and (b) S3TEST. Forecasts start on 1 July 2004.

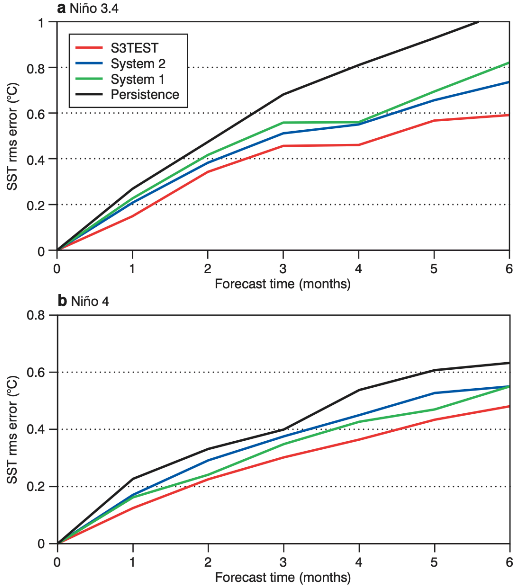


Figure 2 (a) RMS errors for Nino 3.4 SST forecasts from System 1 (green), System 2 (blue) and S3TEST (red), for 64 forecasts in the period 1987-2002. (b) As (a) but for Nino 4. Note that System 2 was worse than the original System 1, but this has more than been made up by S3TEST.

ECMWF Newsletter No. 111 – Spring 2007 **METEOROLOGY**

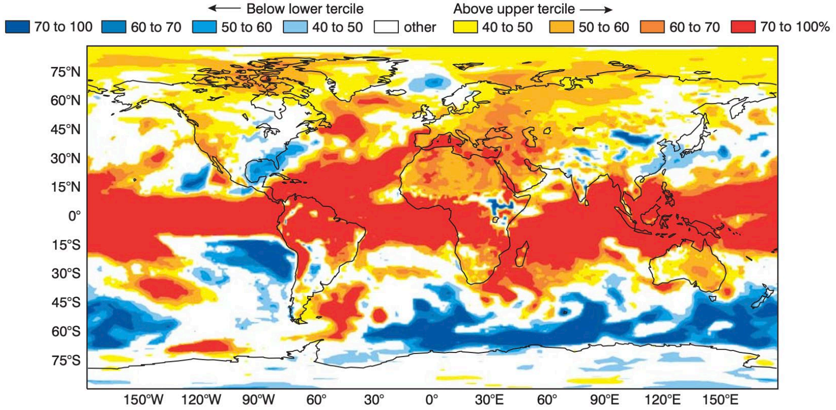
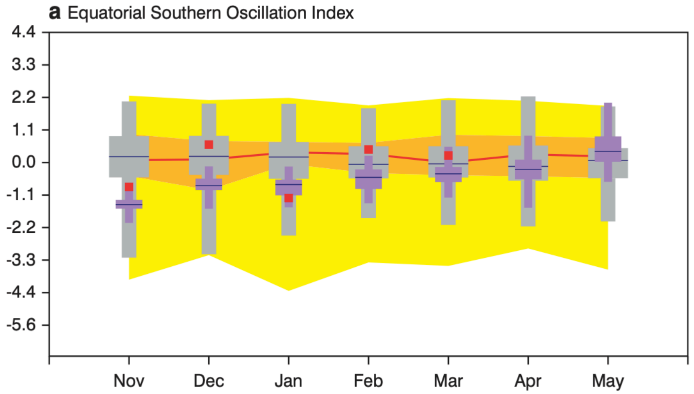
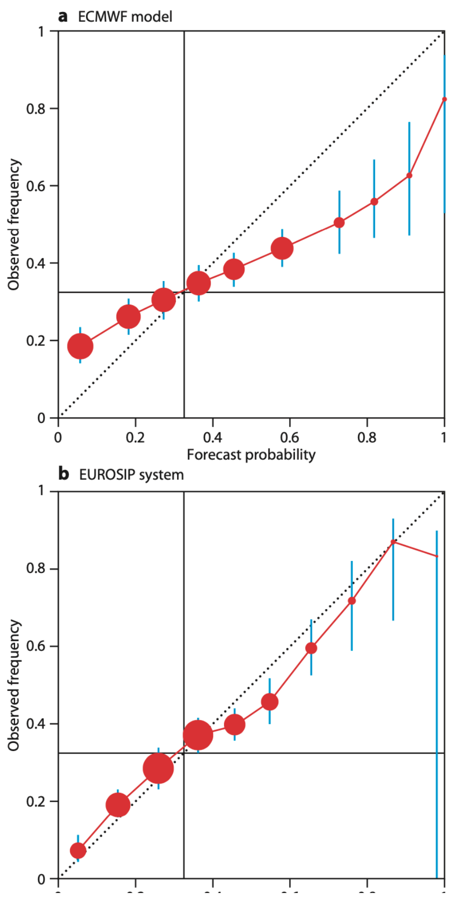


Figure 2 Example of the 'tercile summary' plot for the probabilities of two-metre temperature categories, from the S3 forecast started in December 2006.



EUROSIP – operational multi-model seasonal forecasting

Built on scientific success of DEMETER and ENSEMBLES projects



The present status of EUROSIP

The EUROSIP project presently involves ECMWF, the Met Office and Météo-France as partners – each partner contributes forecasts from a coupled atmosphere-ocean model to the multi-model system. Other organizations from ECMWF Member States or Co-operating States who would like to contribute can request to become EUROSIP partners. The German weather service (DWD) in collaboration with the Max-Planck-Institute for Meteorology intends to join the EUROSIP project in the future. Since spring 2005 graphical products from the multi-model system have been available to users in Member States. A formal data policy for EUROSIP was established by the ECMWF Council in December 2006, and in December 2007 the Council authorized the addition of a selection of EUROSIP multi-model data to the commercial catalogue.

The multi-model system works by combining the data from the operational versions of each contributing model. The main output of the multi-model system is a set of graphical forecast products that are discussed in the next section. Whenever one of the individual models is upgraded, the EUROSIP system will include the updated version. Typically, test data from a new model is made available for several months before the actual operational change, although this is not guaranteed. Each individual model is used to produce forecasts and also a corresponding set of hindcasts (or reforecasts). The hindcast data is used to estimate both model biases and also forecast skill. EUROSIP multi-model products always use the hindcast data corresponding to the real-time forecast data, so when a model version changes a new set of hindcast data is used. Information on the dates of changes in the various model components is available on the web.

In addition to graphical multi-model products on the web, certain EUROSIP products – based on the combined output of all of the models – are made available in digital form. These EUROSIP multi-model products are created together with equivalent hindcast

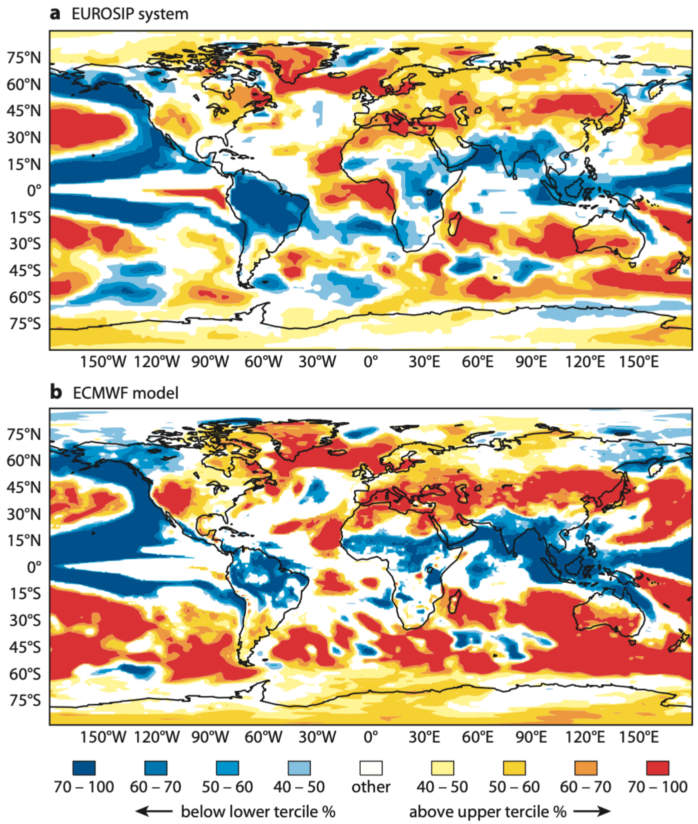
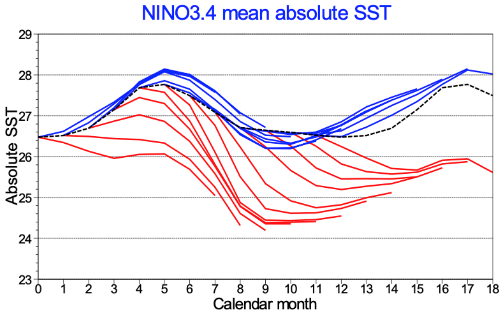


Figure 5 Forecasts for seasonal mean 2-metre temperature tercile categories for June/July/August 2008 from (a) the EUROSIP system and (b) the ECMWF model issued in May 2008. The forecasts are generally consistent, but EUROSIP tends to shift some of the higher probabilities (e.g. 70–100%) downwards towards lower values.

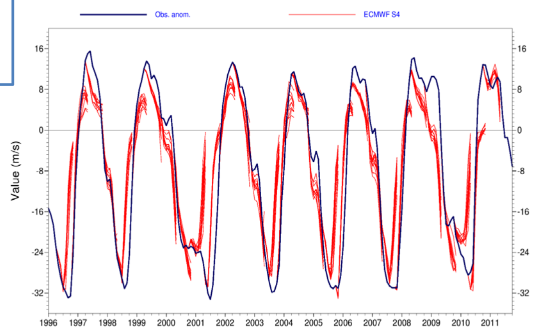
System 4 introduced in 2011

- Switch to NEMO ocean model
  - ocean data no longer in MARS ☹
- Stratosphere resolving (top at 0.01 hPa instead of 5 hPa) - QBO
- Cold bias, ENSO amplitude scaling, improved spread
- 30-year calibration, 51-member real-time ensemble



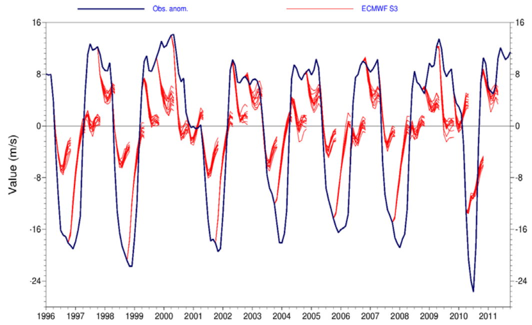
T_L255L91/1°
80 km

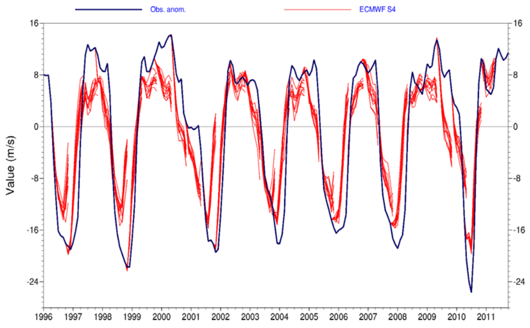
System 4



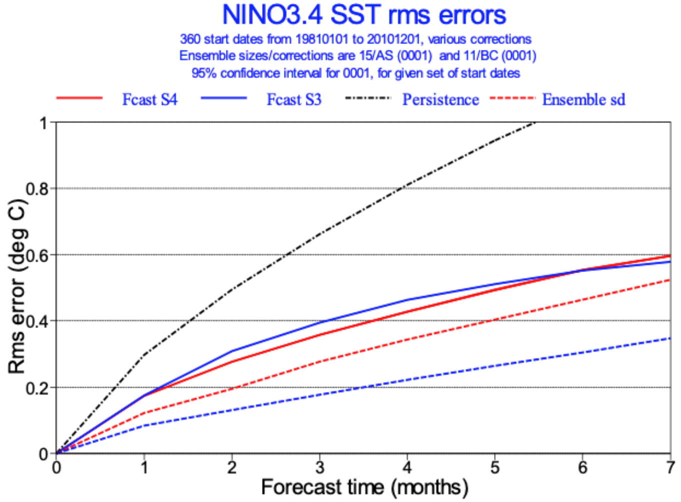
30hPa

System 3





50hPa



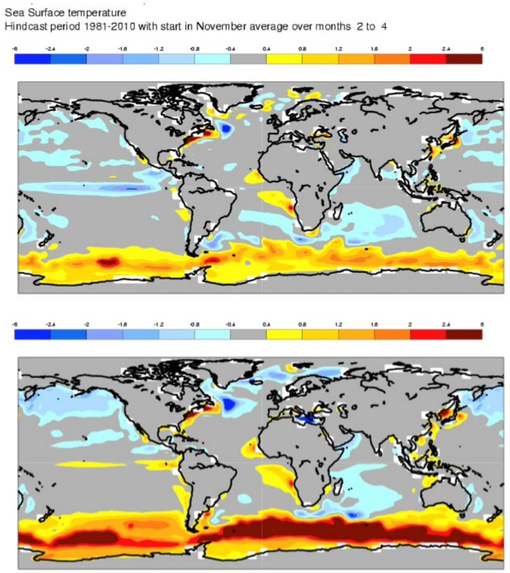
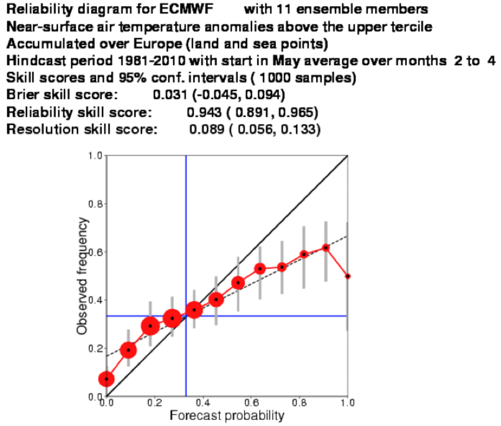


Figure 3.1.1: SST bias in DJF (from November start dates), for S4 (top) and S3 (bottom).



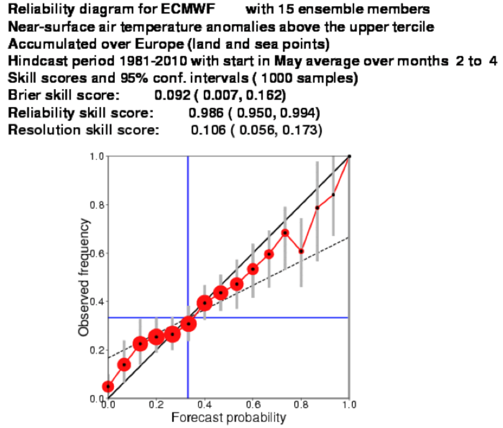
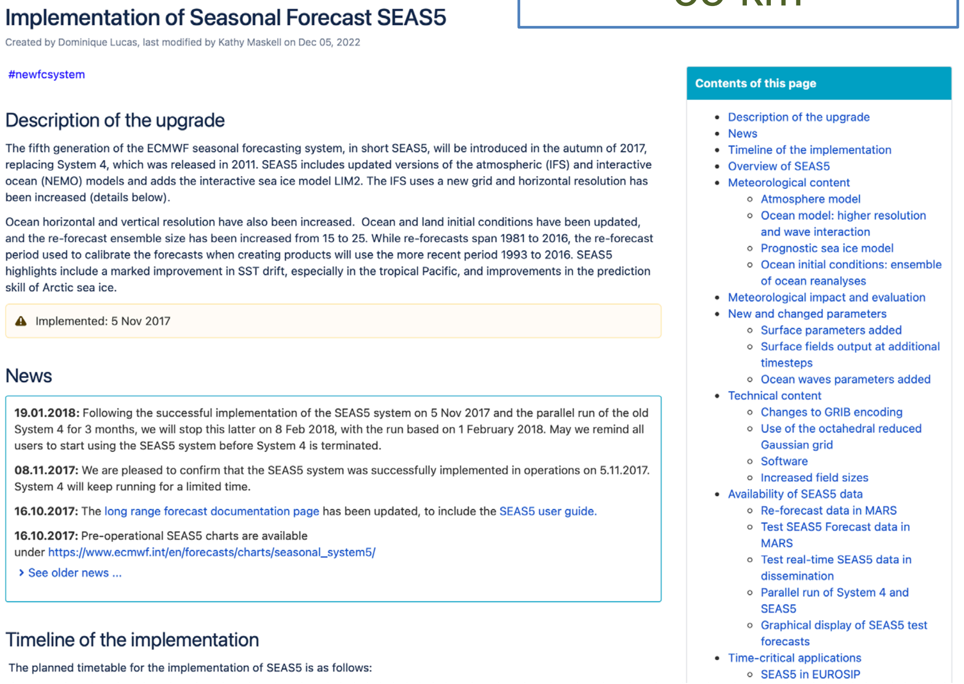


Figure 4.2.3 Reliability diagrams for JJA 2m temperature over Europe in the upper tercile category, for S3 (left) and S4 (right).

SEAS5 introduced in 2017

TCo319L91/0.25°
35 km

- New nomenclature
- Substantial resolution increase for both IFS and NEMO
- Sea-ice modelled and predicted (LIM2)
- More explicit seamless strategy



Implementation of Seasonal Forecast SEAS5

Created by Dominique Lucas, last modified by Kathy Maskell on Dec 05, 2022

#newfcsystem

Description of the upgrade

The fifth generation of the ECMWF seasonal forecasting system, in short SEAS5, will be introduced in the autumn of 2017, replacing System 4, which was released in 2011. SEAS5 includes updated versions of the atmospheric (IFS) and interactive ocean (NEMO) models and adds the interactive sea ice model LIM2. The IFS uses a new grid and horizontal resolution has been increased (details below).

Ocean horizontal and vertical resolution have also been increased. Ocean and land initial conditions have been updated, and the re-forecast ensemble size has been increased from 15 to 25. While re-forecasts span 1981 to 2016, the re-forecast period used to calibrate the forecasts when creating products will use the more recent period 1993 to 2016. SEAS5 highlights include a marked improvement in SST drift, especially in the tropical Pacific, and improvements in the prediction skill of Arctic sea ice.

Implemented: 5 Nov 2017

News

19.01.2018: Following the successful implementation of the SEAS5 system on 5 Nov 2017 and the parallel run of the old System 4 for 3 months, we will stop this latter on 8 Feb 2018, with the run based on 1 February 2018. May we remind all users to start using the SEAS5 system before System 4 is terminated.

08.11.2017: We are pleased to confirm that the SEAS5 system was successfully implemented in operations on 5.11.2017. System 4 will keep running for a limited time.

16.10.2017: The long range forecast documentation page has been updated, to include the SEAS5 user guide.

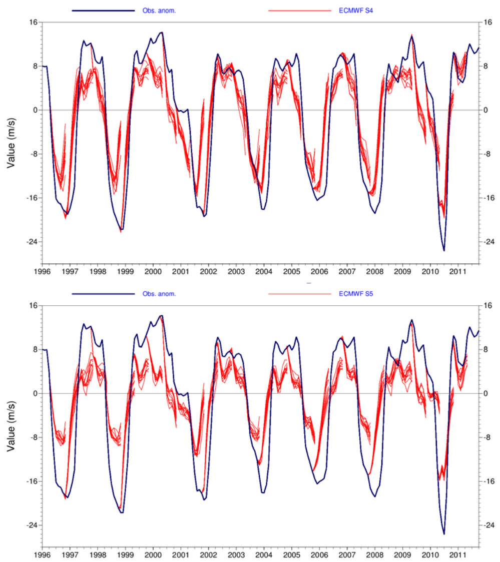
16.10.2017: Pre-operational SEAS5 charts are available under https://www.ecmwf.int/en/forecasts/charts/seasonal_system5/

› See older news ...

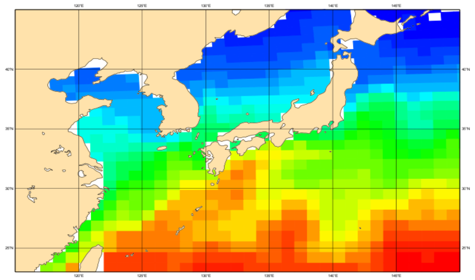
Timeline of the implementation

The planned timetable for the implementation of SEAS5 is as follows:

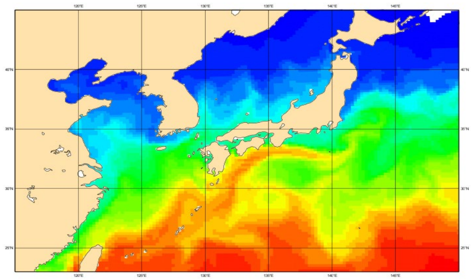
Contents of this page



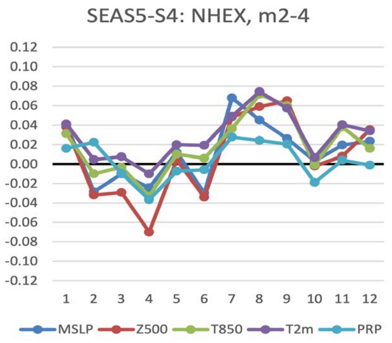
QBO period OK but structure degraded (here 50 hPa)

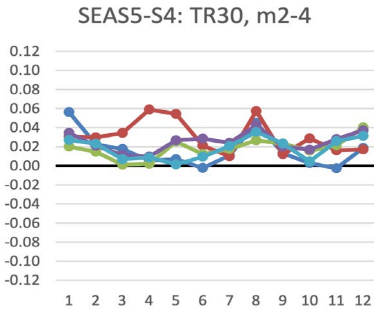


NEMO ORCA1 Z42



NEMO ORCA025 Z75





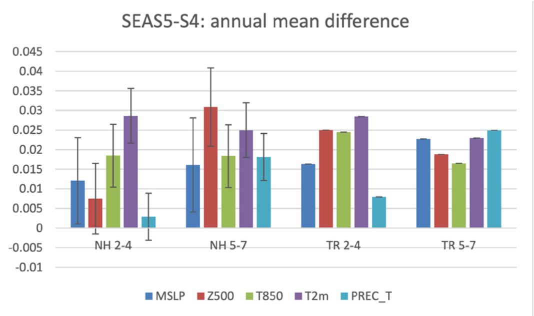


Figure A 4: Annual mean of SEAS5 – S4 differences in aggregated anomaly correlation over NHEX (NH) and TR30 (TR), for re-forecasts verifying at 2-4 month and 5-7 months, based on 1981-2010 15 member re-forecasts. Bars for NH indicate the 1 sigma sampling uncertainty in the correlation difference.

Skill improvement detectable when averaged across all state dates (c.f. Chris O'Reilly's talk)

C3S climate prediction: seasonal timescales

DATA PRODUCTS

cds.climate.copernicus.eu

GRAPHICAL PRODUCTS

climate.copernicus.eu/charts/packages/c3s_seasonal/

- Datasets available in the Climate Data Store
  - Atmosphere
    - daily and subdaily data (6h, 12h, 24h)
    - monthly statistics (mean, max, min, standard deviation)
    - bias corrected data (monthly anomalies)
  - Ocean monthly means
- Multi-system retrospective forecasts and real-time forecasts, the latter published on 6th (ECMWF) and 10th day of month (the rest)

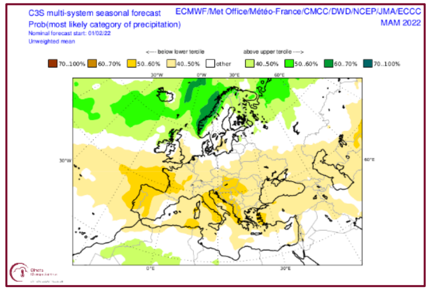
CDS API

```python
import cdsapi

c = cdsapi.Client()

c.retrieve(
    'seasonal-monthly-single-levels',
    {   'format':'grib',
        'originating_centre':'meteo_france',
        'variable':'total_precipitation',
        'product_type':[
            'ensemble_mean','hindcast_climate_mean'
        ],
        'year':'2018',
        'month':'09',
        'leadtime_month':['1','2','3','4','5','6'] },
    'cds_seasonal_output.grib')
```

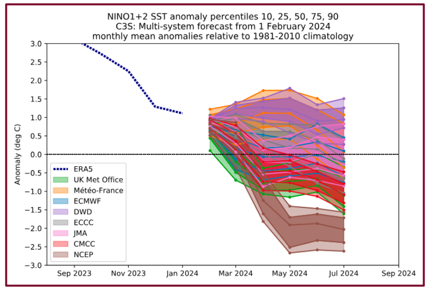
Python workflows

jupyter

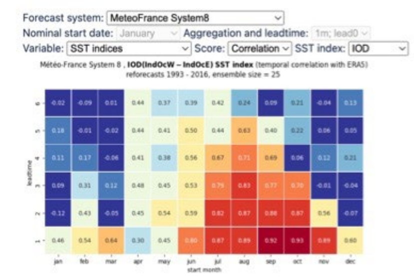
Products for individual contributing systems and multi-system combination



Total precipitation
Near-surface temperature and wind
Mean sea-level pressure
Sea surface temperature
Sea ice concentration
Geopotential height at 500 hPa
Temperature at 850 hPa



Sea surface temperature NINO regions
Sea surface temperature Indian Ocean
Zonal mean wind at 10hPa



Temporal correlation
Relative Operating Characteristic (ROC) score
Ranked Probability Score (RPS)

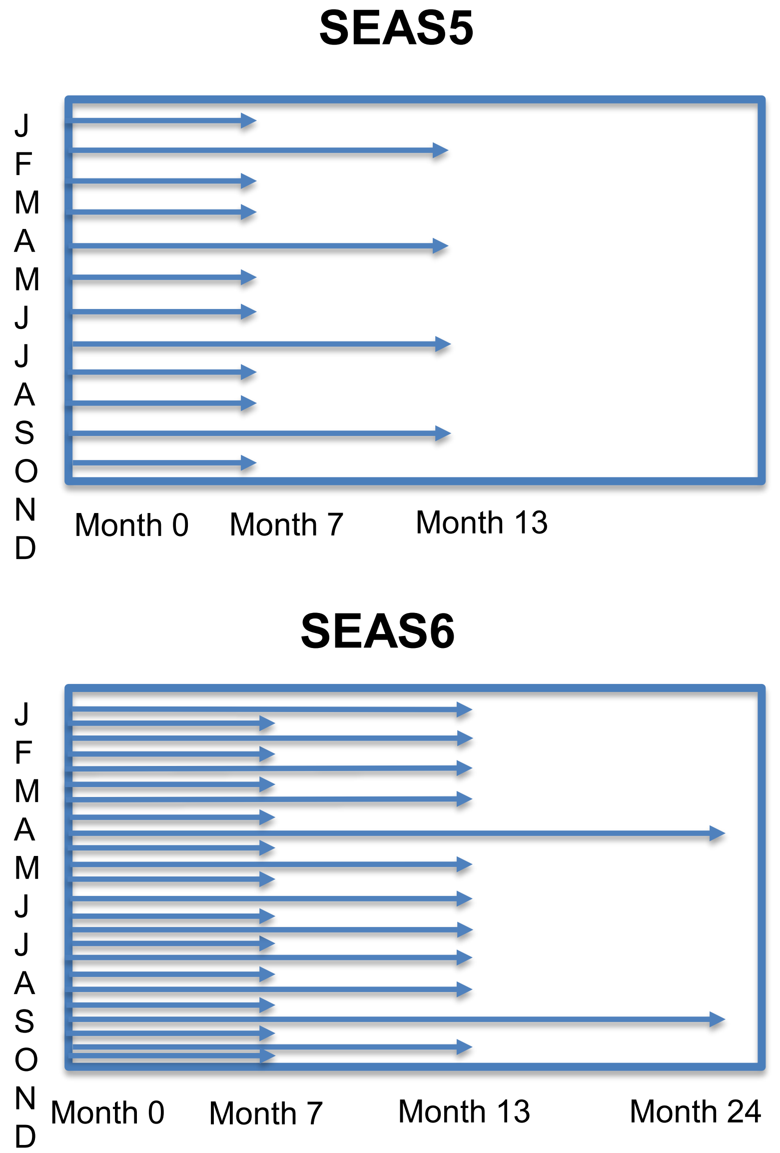
SEAS6 configuration summary

- **Enhancement 1: Real-time 101 member ensemble**

- **Enhancement 2: Issue SEAS twice per month**
  - Initial date 1st and 16th of each month

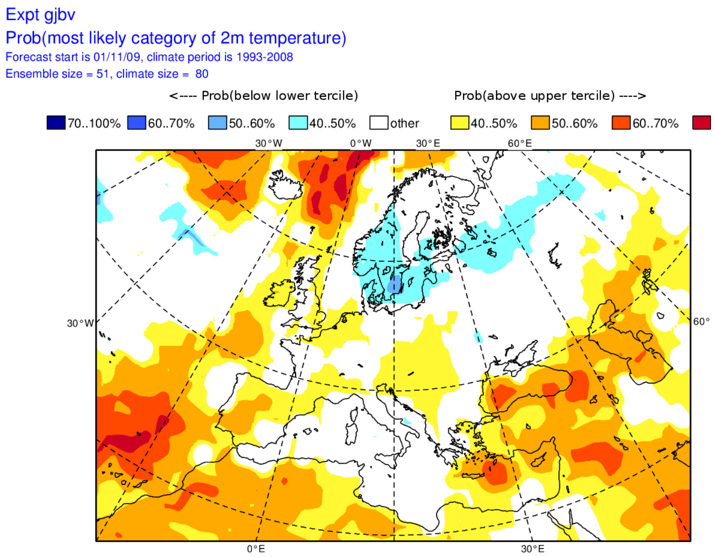
- **Enhancement 3: More comprehensive reforecasts**
  - Larger ensemble sizes and larger set of years

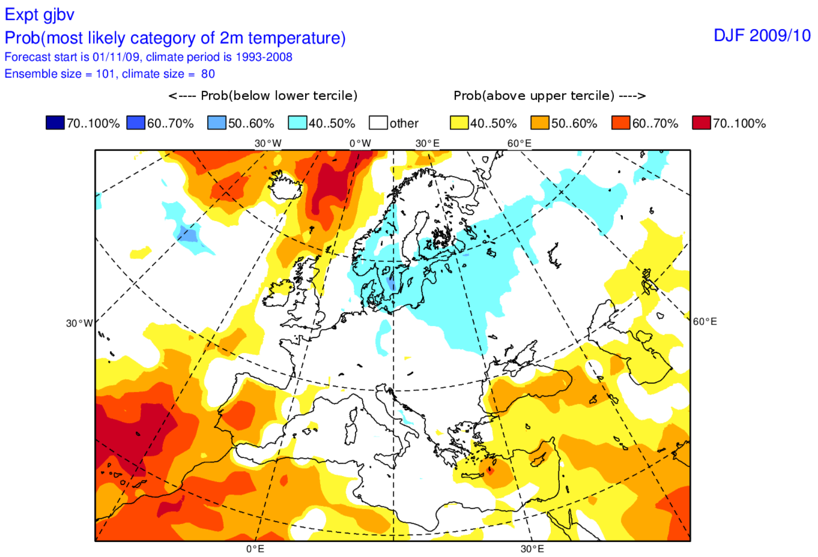
- **Enhancement 4: Expand annual-range ENSO forecasts**
  - Issue forecast monthly not quarterly
  - Twice per year, increase range to 24 months

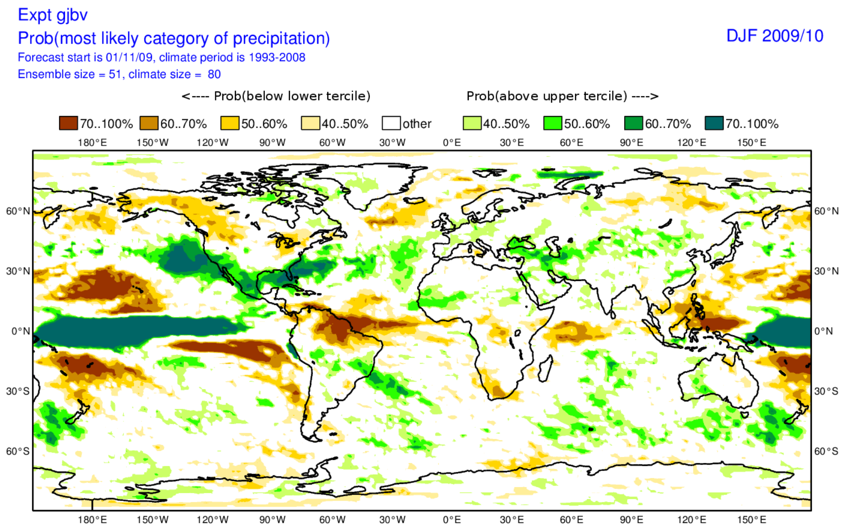


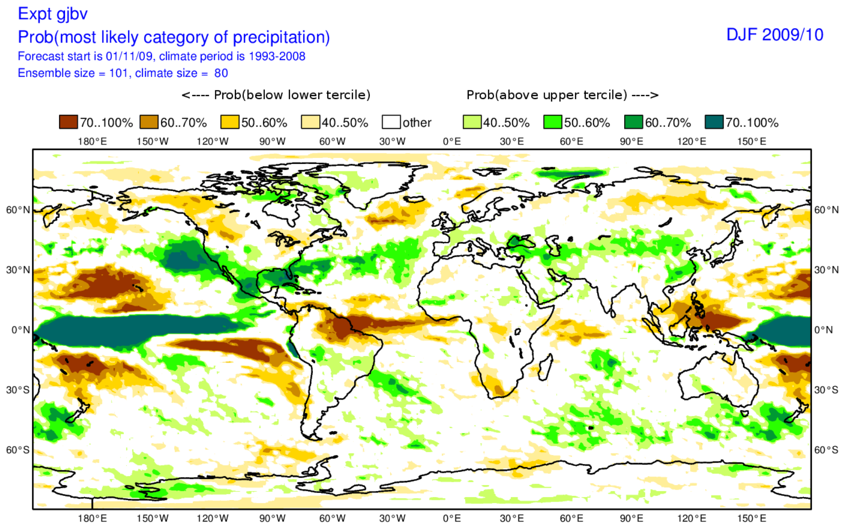
SEAS6 enhancement: 101 member ensembles

- Reduced noise and improved accuracy in forecasts



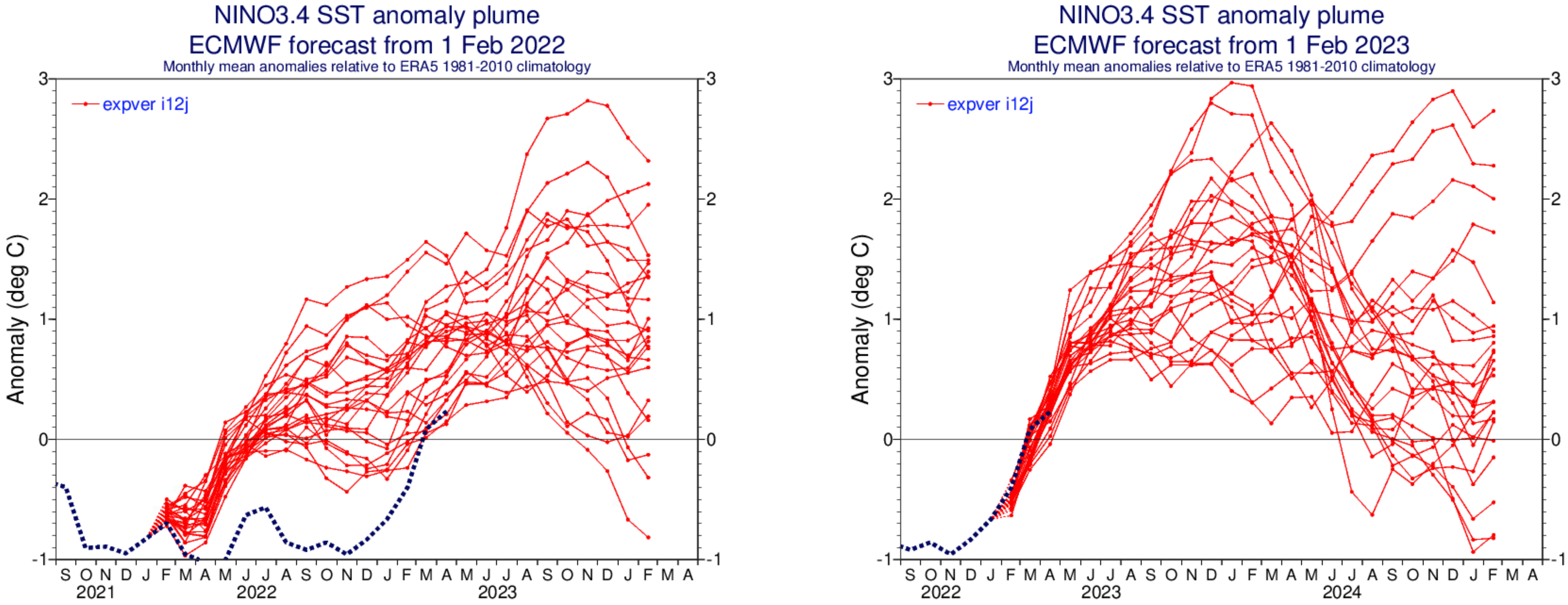






- Number of real-time forecasts << reforecasts, so doubling real-time ensemble size is relatively cheap.

Two-year forecasts: SEAS5-based example for 2023 El Nino

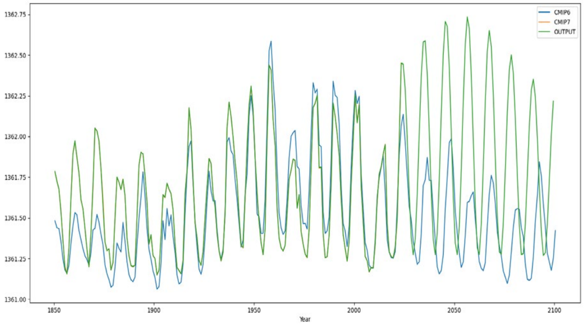


Feb 2022 forecast suggests weak warming in 2022 (which was wrong), followed by likelihood of stronger warming in 2023, with the possibility of a strong El Nino

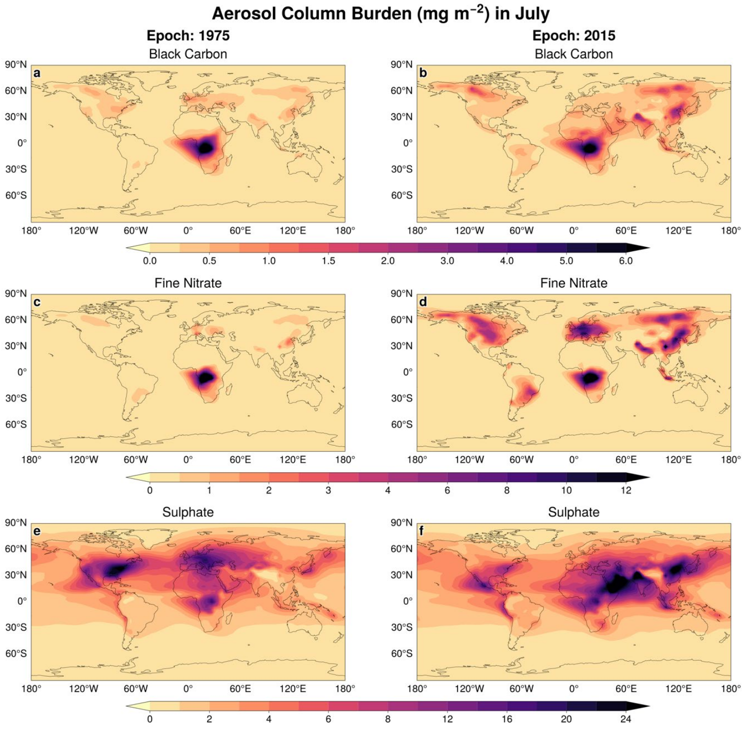
Feb 2023 forecast is for a moderate to strong El Nino in 2023, with a strong event followed by a return to neutral or La Nina conditions; but the possibility of a moderate warming strengthening to give a strong 2-year event.

SEAS6 science

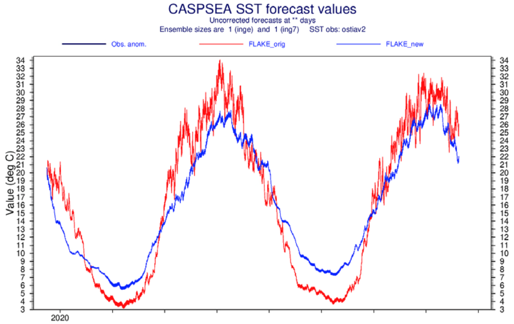
- Major new ocean reanalysis
- Dedicated land surface analysis/reanalysis
- L137, improved stratospheric processes
- Time varying tropospheric aerosol
- Improved solar, volcanic forcings



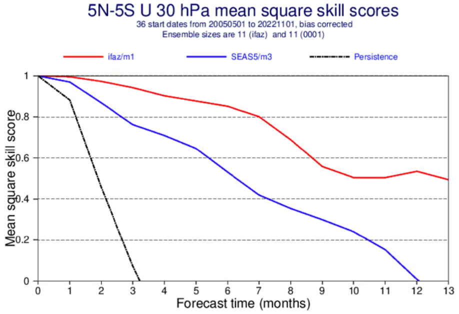
Updated solar forcing

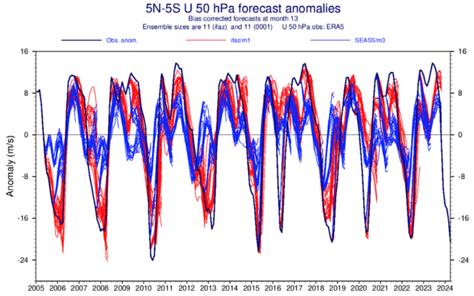


Time-varying aerosol climatology

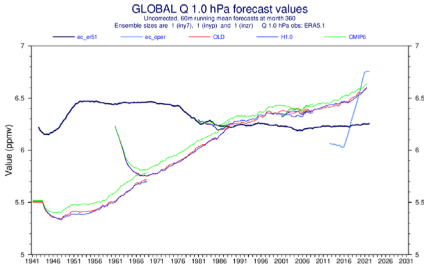


Revised lake model

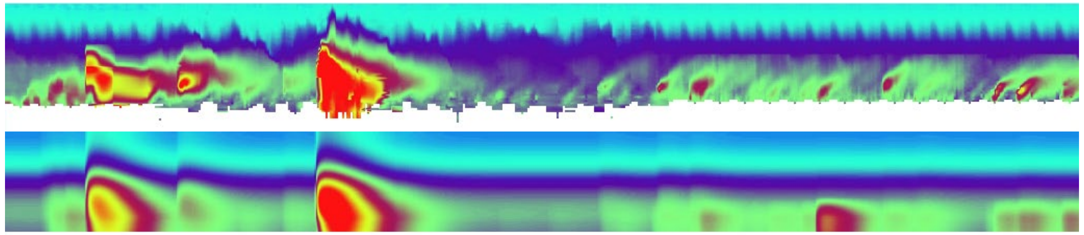




Improved QBO



Improved stratospheric humidity


Volcanic aerosol extinction, from GloSSACv2 (top) and EVA_H (bottom)

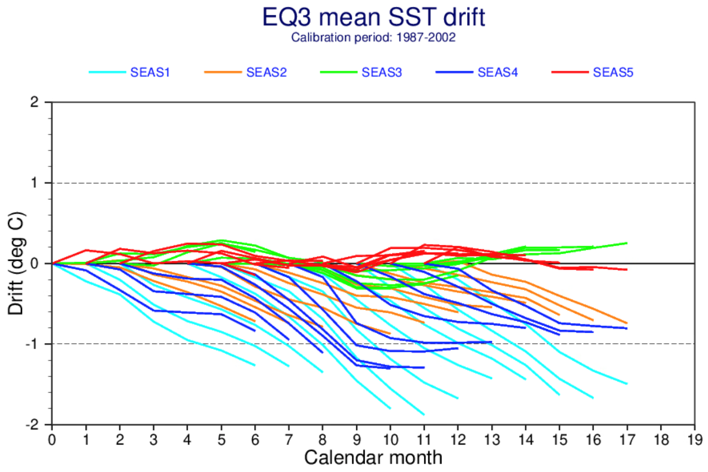
Forecast skill: TBC

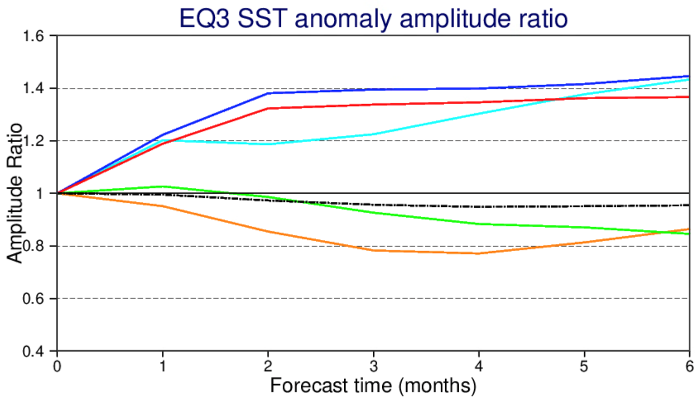
Part 2: Where are we going?

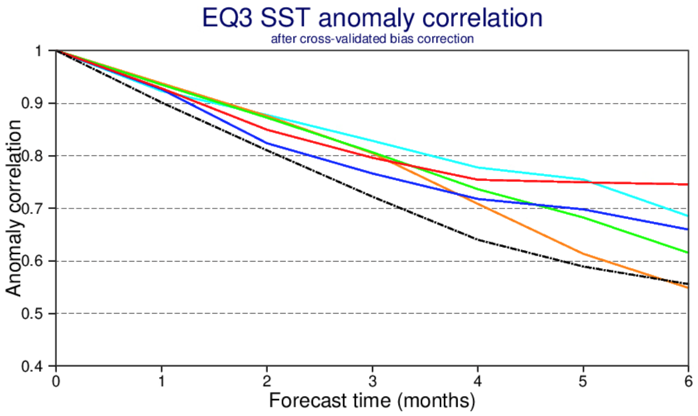
Limiting factors: physics-based models are just not good enough

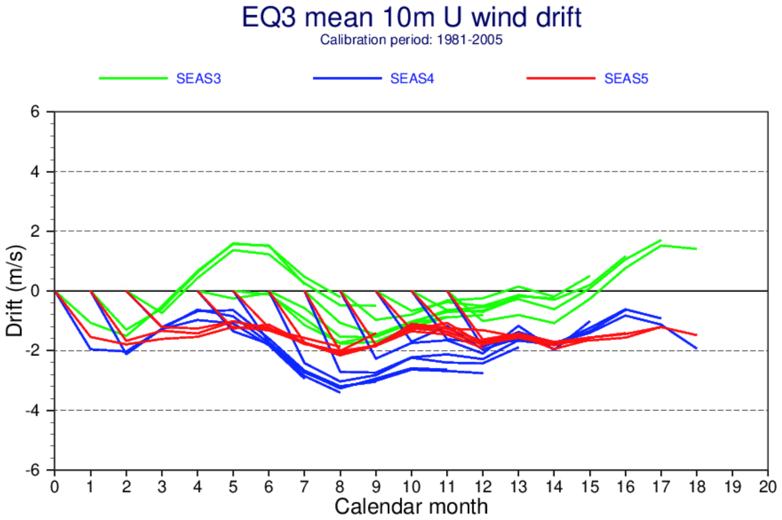
- Biases and trends

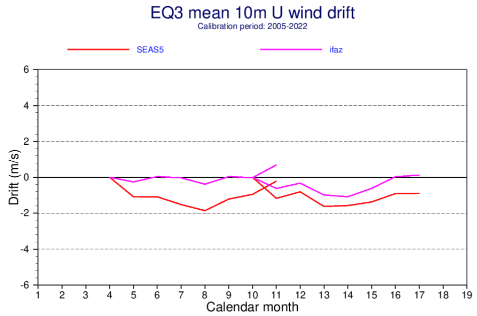
Physics-based models are (still) not good enough: bias

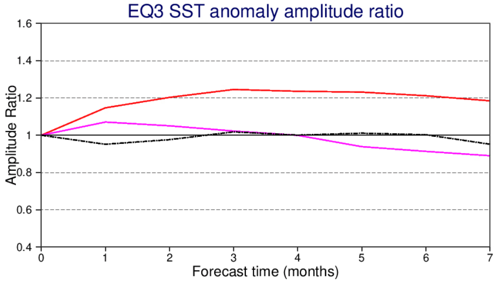


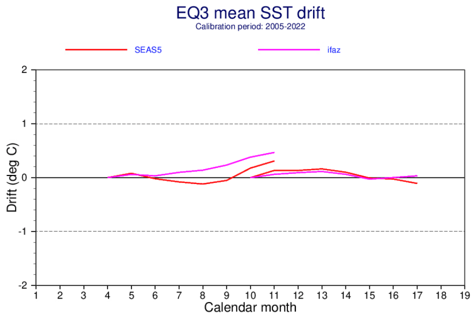


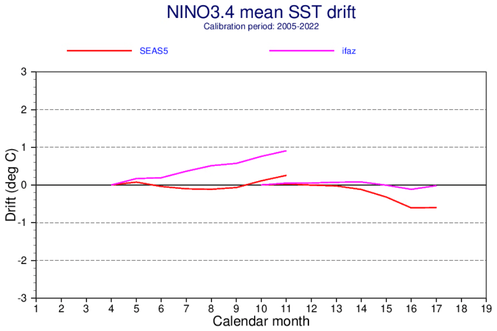








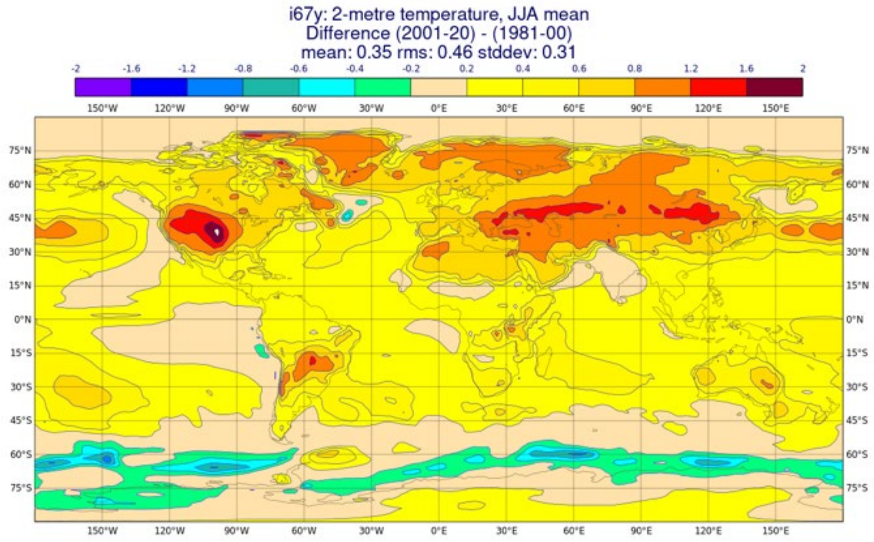


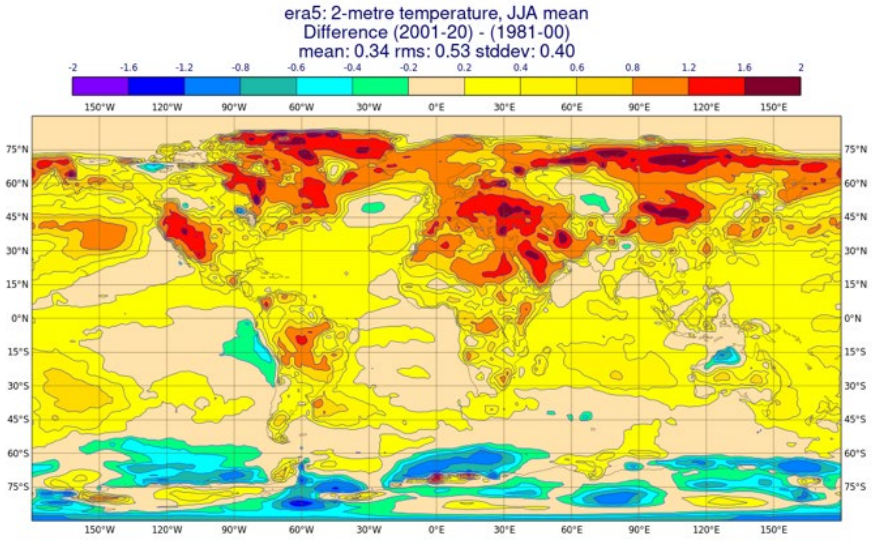


SEAS6 **prototype**:

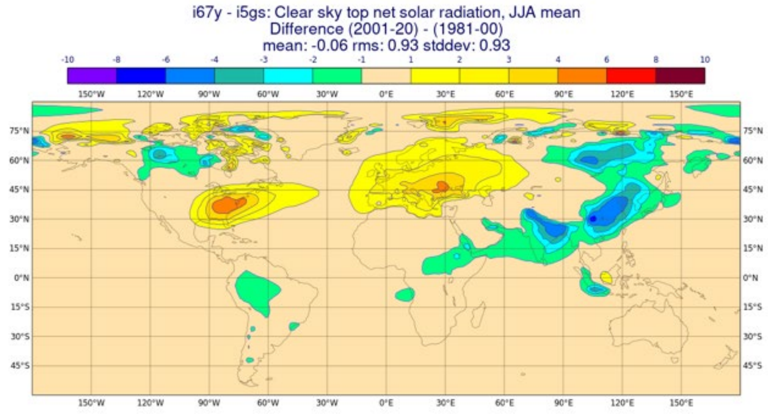
- subject to revision
- 2005-2022

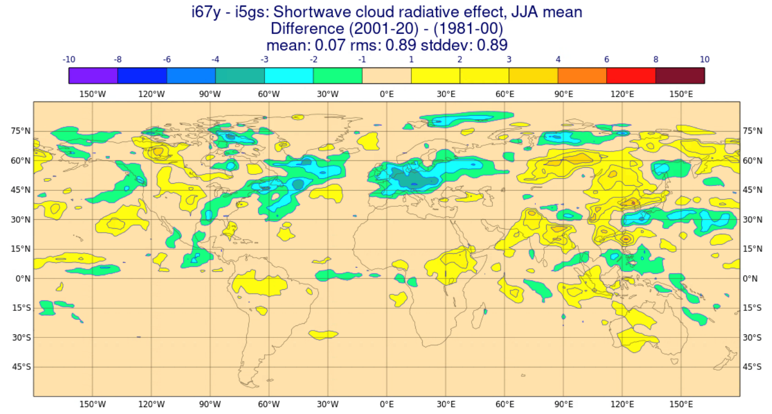
Temperature trends (2001-2020) – (1981-2000)





Forecast trends over Europe (left) less than observed (right)





Changes in clear-sky radiation are plausible, but are opposed over Europe by cloud feedbacks with the wrong sign.

Part 2: Where are we going?

Limiting factors: physics-based models are just not good enough

- Biases and trends
- Question marks over predictability
- Complexity and big science: high cost and slow pace of improvement
- Computing resources – an issue for research

Does ML help?

Limiting factors: Can ML do better than physical-based models?

- ML-based models
  - Physical model biases develop very quickly in the tropics due to our inability to model fast processes.
    - ML-based models have lots of observations / satellite-informed reanalyses to learn fast processes from. To the extent that this enables us to better model the tropics, mean-state, and teleconnections, we might expect a step-change improvement in seasonal prediction to be possible. E.g.100 years of progress under BAU, in the next 1-2 years. Will ERA6 give better tropical reanalyses that give us even more progress? ✅
  - Question marks over predictability
    - Unknown whether ML can help. Reanalyses may miss a lot of what is happening (e.g in the tropical UTLS, stratospheric waves). Or the issues may even be very subtle fluid dynamics. Might mean-state improvements give more realistic predictability characteristics? ?
  - Complexity and big science: high cost and slow pace of improvement
    - ML should help here, able to sidestep a lot of detailed process modelling where we have observations instead. On the other hand, we have **a lot** to learn on how to put everything together, and ML is likely to enable a lot of new science ☺ ✅
  - Computing resources
    - ML is good for large ensembles (although at seasonal resolutions the gain may be only large). Just at the moment GPUs are *sauteuer*, but that should ease. Training costs still an issue, but overall should help. (✅)

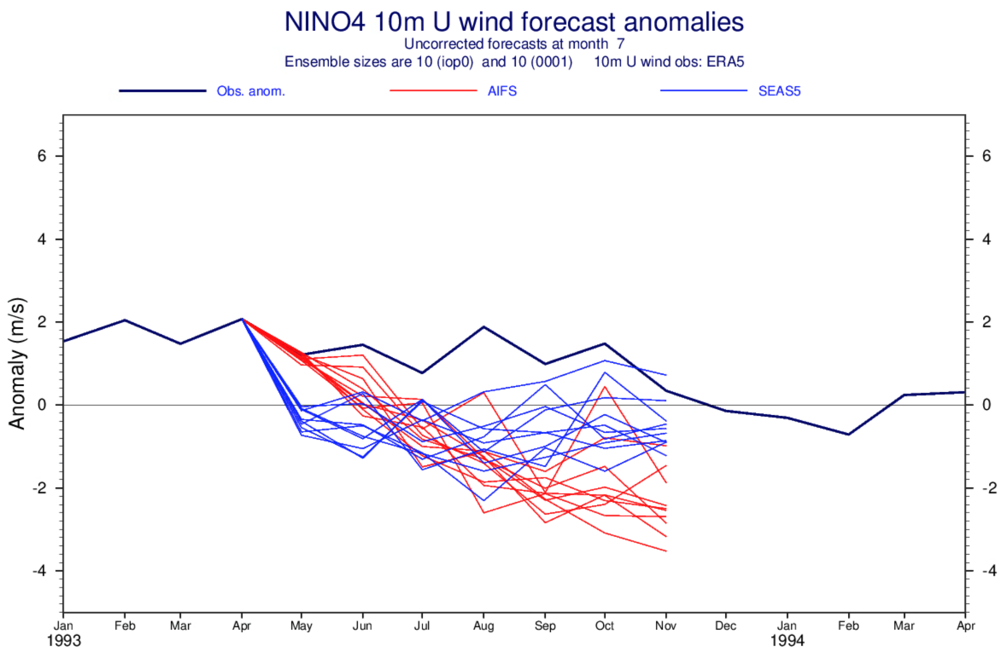
Seasonal AIFS – work is underway

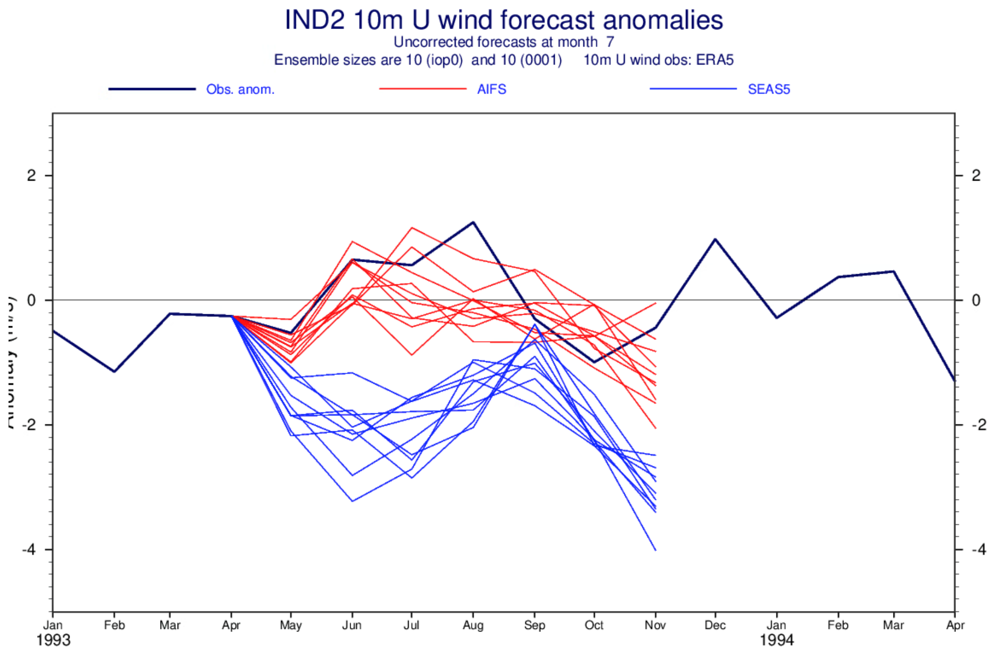
Short term goals: use AIFS to improve tropical (and extra-tropical?) response to SST

> Might end up with SEAS6A to go alongside SEAS6

Medium-term goals: “somehow” build either a full ML or hybrid seasonal forecast system

> Fundamental limitation is **information,** so combine best of data-driven and physically modelled

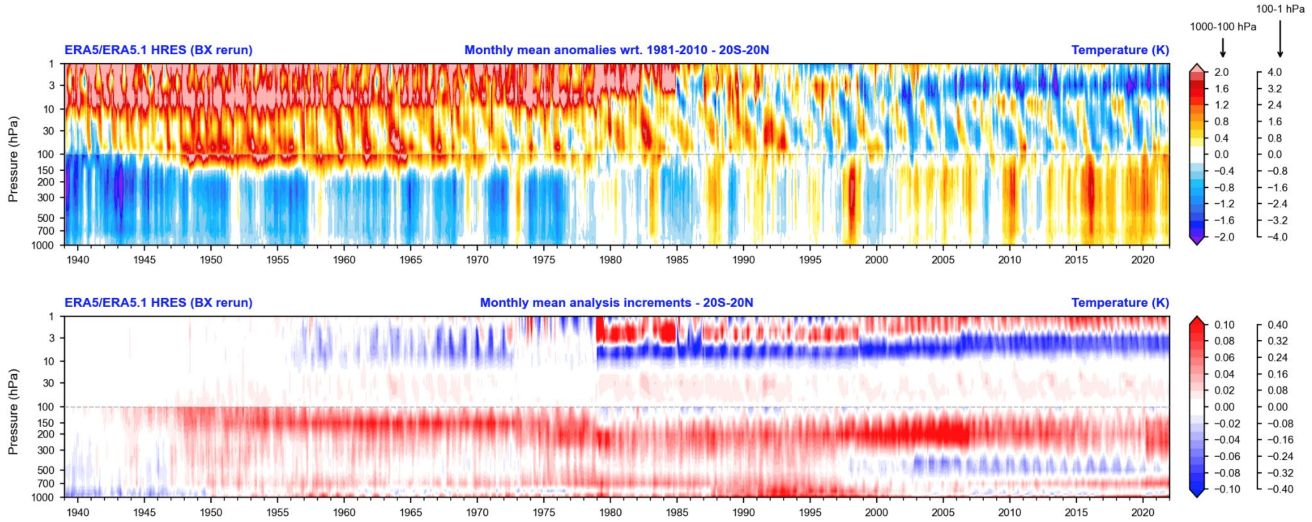




Limiting factors: reanalyses and sampling

- To calibrate and assess skill, we need lots of cases => need long reanalyses
  - We are limited by observational data as we go back in time
  - Non-stationarity a challenge (c.f. Ante Weisheimer’s talk)

- Would better models help with reanalysis?
  - Quite possibly, but for that we have to deal with another limiting factor ...



What caused the warm tropical tropopause (constrained by radiosonde data) in the 1950s and 60s?
Are CMIP6 ozone estimates wrong?

Limiting factors: forcings and climate change

- Climate forcings are changing over time
  - We need accurate representation of past changes
    - to enable unbiased reanalyses with patchy data
    - to enable consistent reforecasts made across multiple decades
  - We need accurate representation of the present and near-future
    - Critical for the proper calibration of our real-time forecasts
  - Climate forcings are also a modelling problem, e.g. cloud/aerosol feedbacks
- Climate forcings in the past
  - Stratospheric ozone, humidity, land changes, aerosol emissions
- Climate forcings in the present
  - Cloud aerosol feedback uncertainty
  - Solar uncertainty
  - Volcanic eruptions

Limiting factors: forcings and climate change

- Real-time forecasts are **vulnerable** to errors in our modelling of the changing climate
- Reanalyses can struggle where we are uncertain of past forcings

- These are fundamental science questions, ML is of little direct help
- But maybe ML **can** help with short-term trend calibration?

Prospects for progress

- Business as usual
  - Prospects for continued slow forecast improvement over coming decades.
  - Better outputs (as per SEAS6, larger ensembles, more frequent updates, product development)
  - Value of even limited quality seasonal forecasts may be higher due to impact of fast-changing climate
  - Still very worthwhile

- What can AI and ML revolution bring?
  - Better models
  - Alternative views in operational multi-systems
  - Scientific challenge of melding different timescales, data rich / data poor processes and limited samples
  - Scientific challenge of dealing with poorly modelled/understood changes in climate forcings