Overview of the ECMWF long-range forecasting system

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ECMWF

Approaches to seasonal forecasting

- Empirical, low-order model or ML-based forecasting
    - Use past observational record and statistical methods
    - Works with reality instead of error-prone numerical models ☺
    - Aim to extract predictable signals, and represent uncertainty in outcome ☺
    - Limited number of past cases: works best when observed variability is dominated by a single source of predictability ☹
    - Limited quality of past data is a problem for some sources of predictability ☹
    - A non-stationary climate is problematic ☹
- Full-physics numerical forecasts
    - Include comprehensive range of sources of predictability ☺
    - Non-linear interactions of oceanic, land and atmospheric sources of predictability ☺
    - Benefit from latest observing systems, use all information about the present state ☺
    - Ensemble forecasts map uncertainty in initial state to uncertainty in outcome ☺
    - Model errors are an issue! ☹

Sources of seasonal predictability

- KNOWN TO BE IMPORTANT:
  - El Nino variability - biggest single signal
  - Other tropical ocean SST - important, but multifarious
  - Climate change - impact is substantial, especially in temperature forecasts, and must be accounted for
  - Local land surface conditions - e.g. soil moisture in spring: dry soil warms up more quickly and is more prone to drought

- OTHER FACTORS:
  - Volcanic eruptions - important for large events, gives global cooling plus sometimes a winter warming in parts of the northern hemisphere
  - Mid-latitude ocean temperatures - Convergence near SST fronts?
  - Remote soil moisture/ snow cover - Unclear how large the effects might be
  - Sea ice anomalies - definitely local effects, also weaker remote impacts
  - Dynamic memory of atmosphere - most important for first month
  - Stratospheric influences - polar vortex, QBO, solar cycle, ozone, …
  - Aerosols - natural and anthropogenic
- Unknown or Unexpected - e.g. smoke from forest fires, other unexpected events ??

Key ingredients of operational seasonal NWP system

1. A good numerical model (should be nearly perfect, but it won't be)

2. Initial conditions
   - For the past
   - For real-time forecasts (should be nearly perfectly consistent in time, this is hard)

3. A set of re-forecasts (large and expensive)

4. Operational real-time forecasting and product generation (needs to be reliable)

SEAS5 forecast model

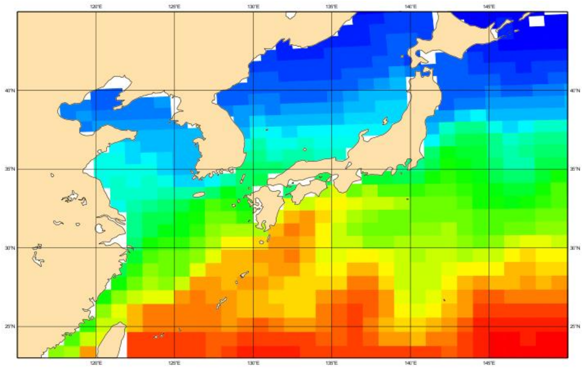
- IFS (atmosphere and land surface)
  - TCo319L91 Cy43r1, 35km grid for physics, full stratosphere
  - All of the physical and dynamic processes of a world-class NWP model
  - Land surface model, multiple soil layers, different soil types, different vegetation types, snow, glaciers
  - Lake model with variable depths, variable mixed layer, surface and bottom temperatures, lake ice
  - Time varying tropospheric sulphate aerosol and stratospheric aerosol from volcanoes
- Wave model
  - Ocean surface waves modify the interaction between ocean and atmosphere. Runs at 0.5 deg resolution.
- NEMO (ocean)
  - Global ocean model, 0.25 deg resolution (eddy permitting), 75 vertical levels
- LIM (sea-ice)
  - Single category ice, solved on same grid as ocean model

SEAMLESS STRATEGY: SAME MODEL AS MEDIUM/EXTENDED RANGE FORECASTS*

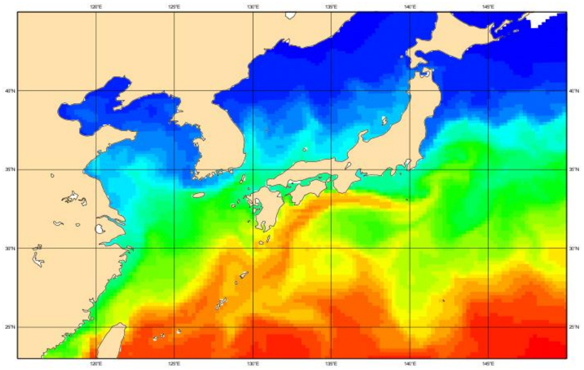
*in reality, almost identical, when introduced

SEAS5 – ocean component

- Ocean model resolution upgraded from previous 1x1 deg to 0.25x0.25 deg
- Ocean vertical resolution improved from previous 42 levels to 75 levels
- High ocean resolution is needed to represent ocean eddies, and to better resolve the boundary currents that are important in the ocean, such as the Kuroshio in the Pacific (shown here) and the Gulf Stream in the Atlantic.



NEMO ORCA1 Z42

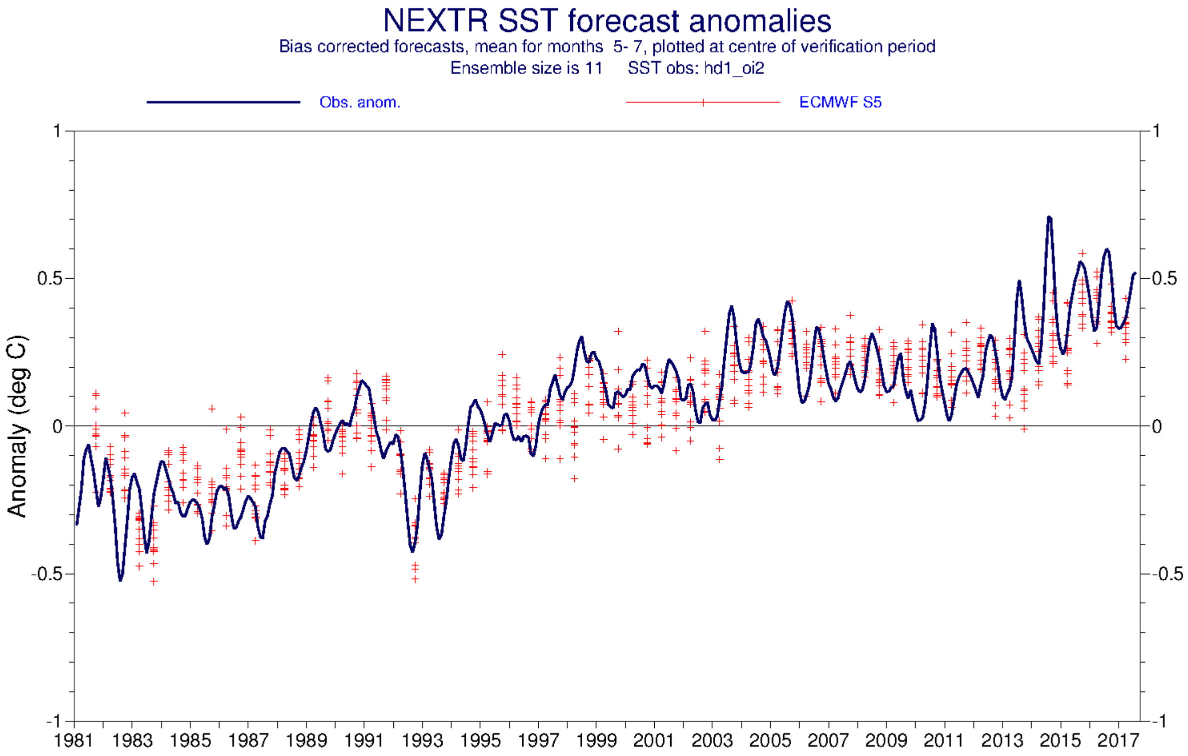


NEMO ORCA025 Z75

Note: ¼ degree ocean resolution is not enough to resolve eddies or boundary currents properly.

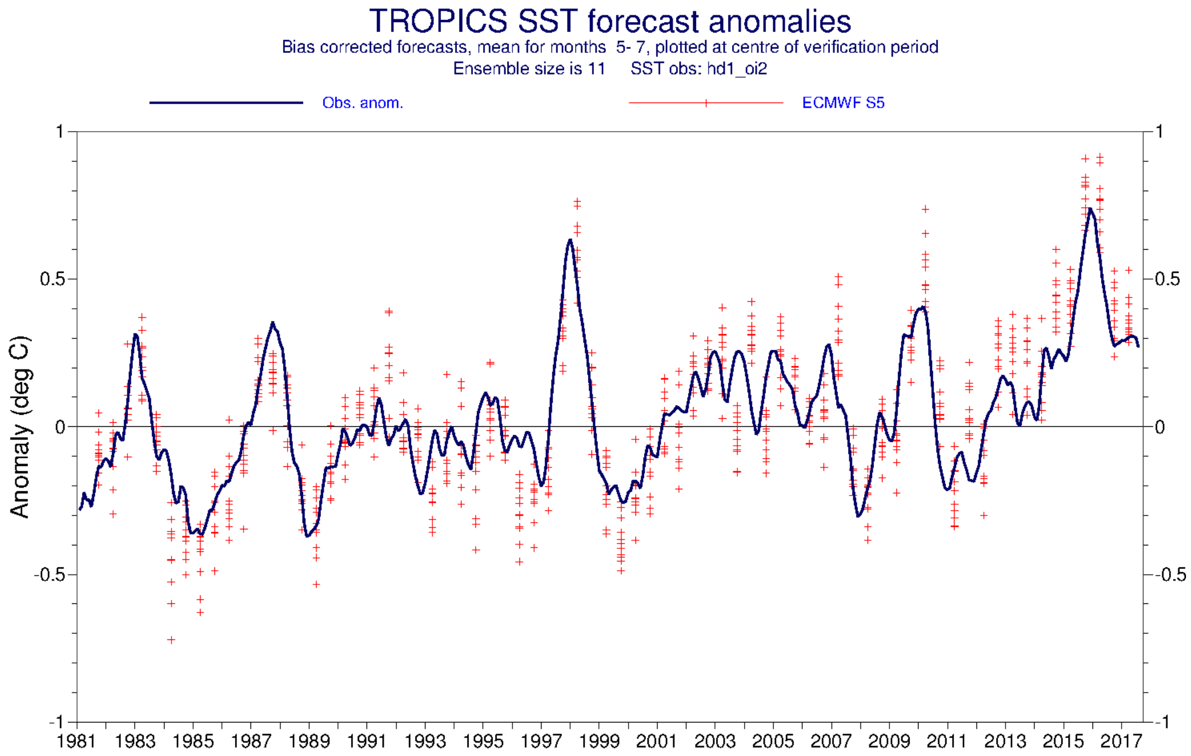
1/12 degree would be nice, but is unaffordable

Trends



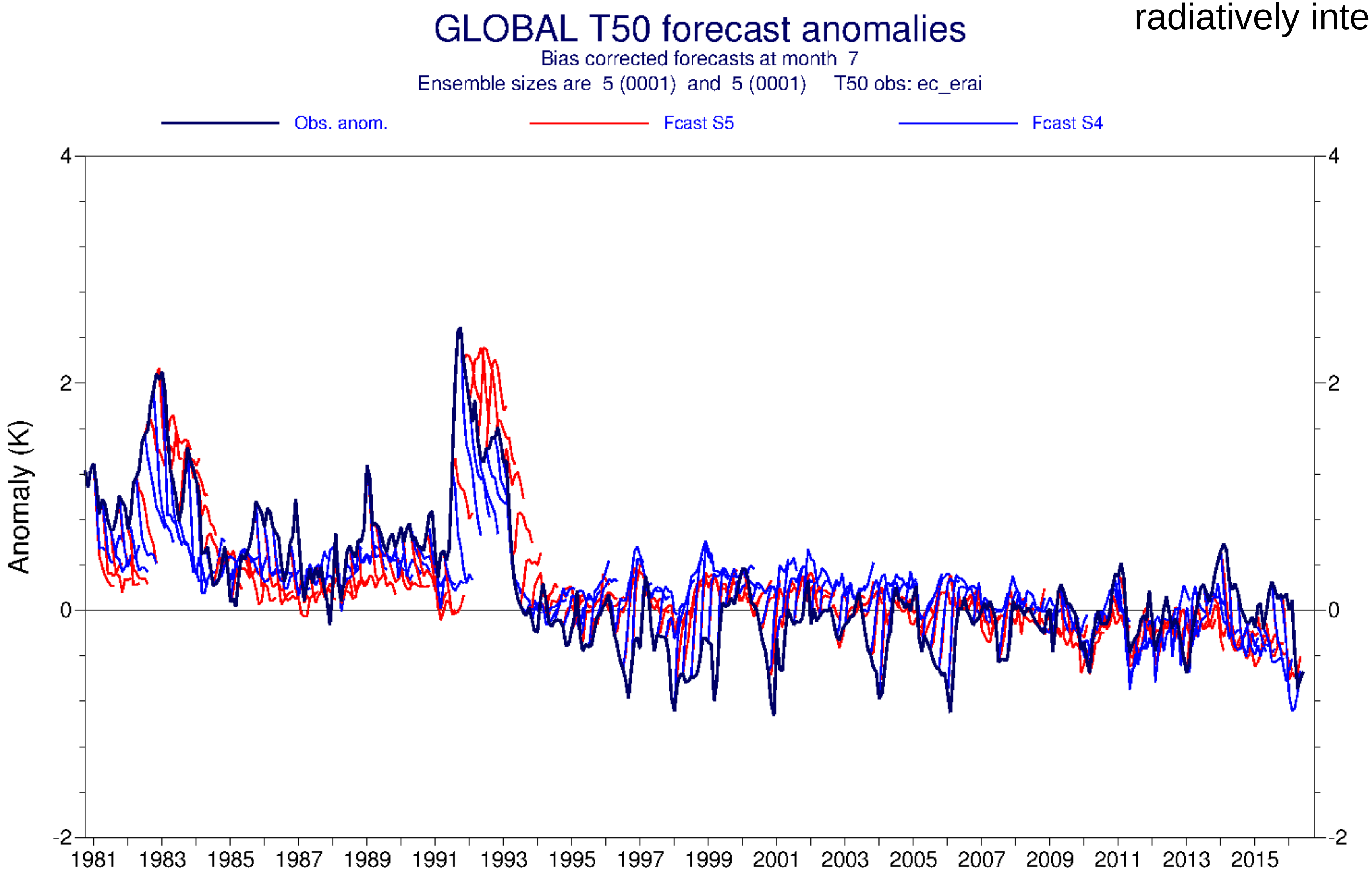
Capturing trends is important. Time-varying CO2 and other factors are important in this.

There is a strong link between seasonal prediction and decadal/ multi-decadal climate prediction.



Stratosphere – volcanic aerosols

SEAS5 does **not** have radiatively interactive ozone



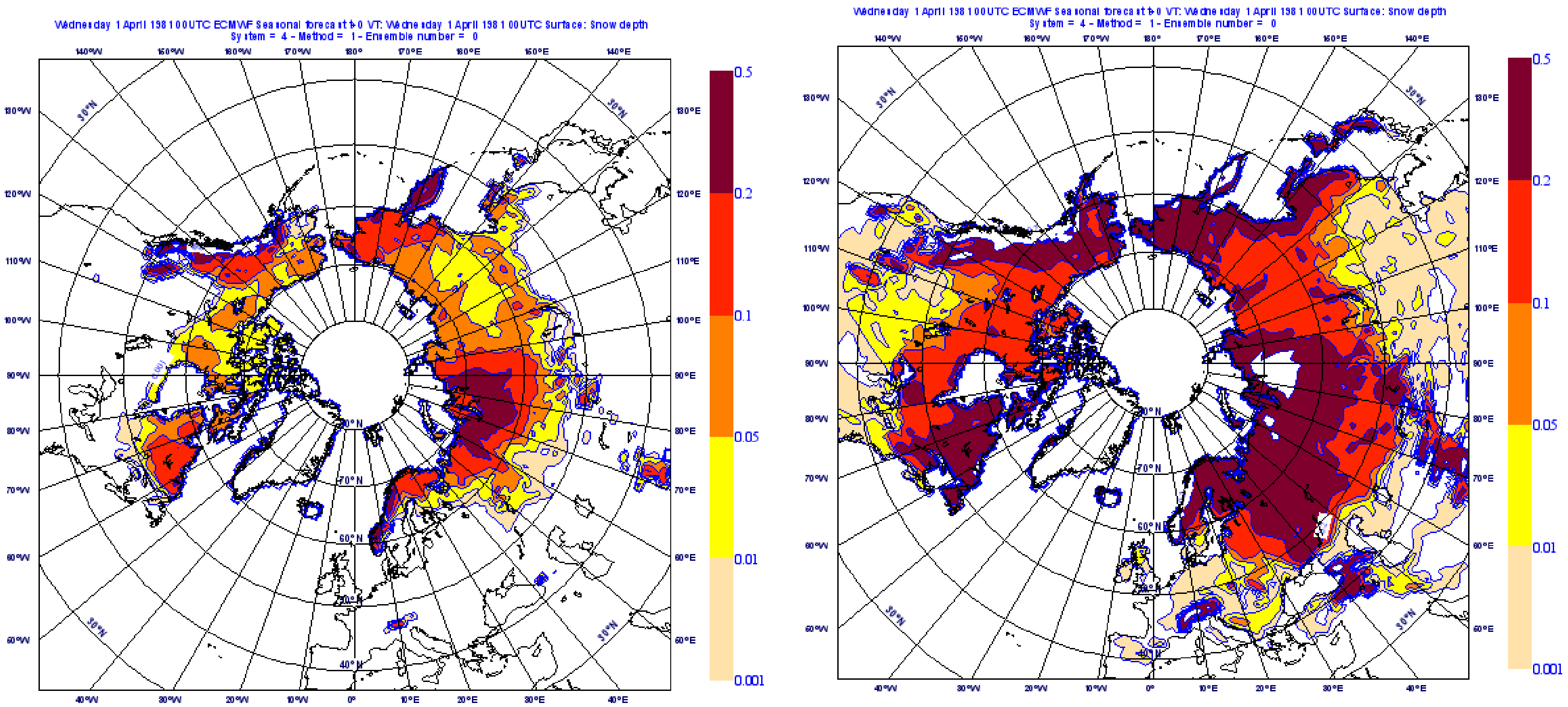
SEAS5 initial conditions

- Ocean – ORAS5 and OCEAN5
  - Biggest source of information on interannual variability, especially ENSO and low-frequency variability
  - OCEAN5 has a behind-real-time (BRT) and near-real-time (NRT) mode
  - Ocean observing system has evolved **a lot** over last 30-40 years
- Land-surface
  - Use ERA interim and operations, with constraints (see next slide)
  - SEAS6 will have dedicated offline land surface re-analysis and real-time analysis to avoid interpolation
- Atmosphere
  - Use ERA interim and operations.
  - SEAS6 will use ERA5 and operations. May use special dataset for stratospheric humidity for reforecasts.

- Initial condition uncertainty
  - SST (50 perturbations), ocean sub-surface (5 member analysis), atmosphere (singular vectors, EDA), but no land perturbations in SEAS5.

Initial conditions - land surface, SEAS5 and earlier

Each surface field has defined permitted maximum and minimum values for each grid-point, based on reanalyses. Used as a safeguard to ensure consistency between real-time and re-forecast initial states. Applied to soil moisture, snow, lakes, soil temperatures. Specific to seasonal configuration.



Snow depth limits, 1st April

ECMWF SEAS5 forecasts and re-forecasts

- Real time forecasts:
  - **51 member ensemble forecast to 7 months**
  - SST and atmosphere initial perturbations (SV, EDA) added to each member

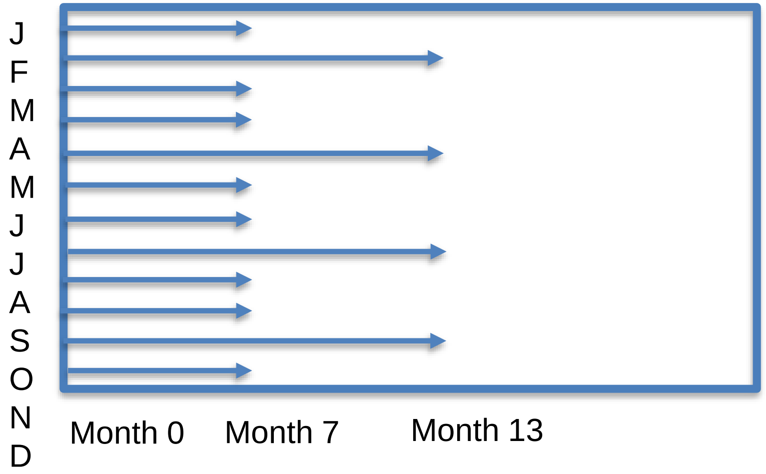
  - **15 member ensemble forecast to 13 months**
  - Designed to give an 'outlook' for ENSO
  - Only runs once per quarter (Feb, May, Aug and Nov starts)

- Re-forecasts from 1981-2016 (**36 years**)
  - **25 member** ensemble every month
  - 15 members extended to 13 months once per quarter

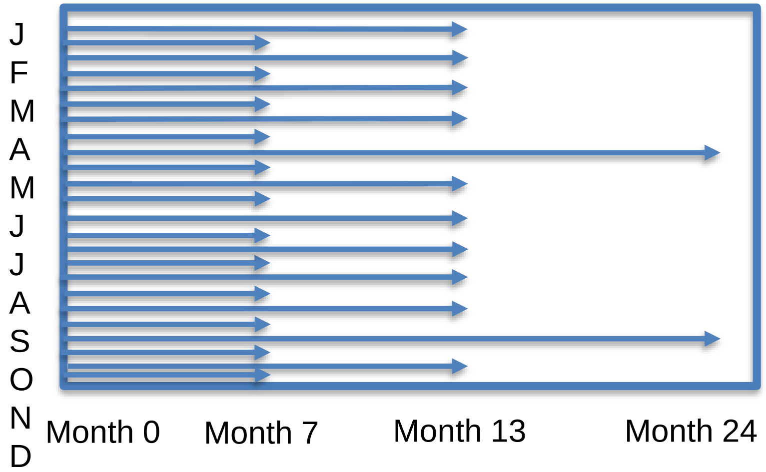
SEAS6 configuration summary

- **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

SEAS5



SEAS6



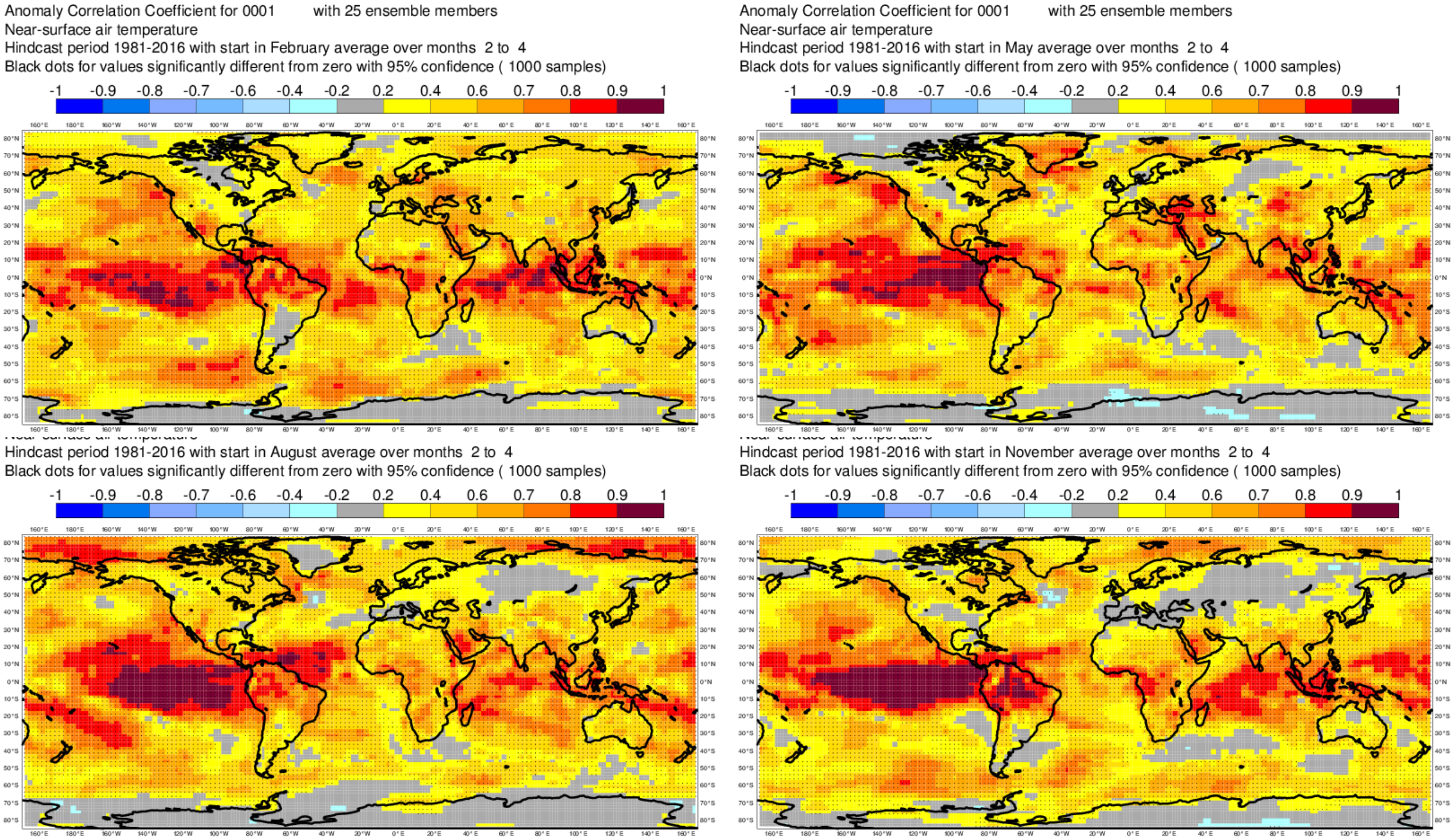
How many re-forecasts?

- Re-forecasts dominate total cost of system
  - SEAS5: 10800 re-forecasts (must be in first year)
    612 real-time integrations (per year)
- Re-forecasts define model climate
  - Need both climate mean and the pdf, latter needs large sample
  - May prefer to use a “recent” period (SEAS5 has 36 years available, but uses only last 24 years for web products)
  - SEAS5 has 600 member climate (25 members * 24 years) for web products, so sampling is basically OK
- Re-forecasts provide information on skill
  - A forecast cannot be used unless we know (or assume) its level of skill
  - Observations have only 1 member, so large ensembles are less helpful than large numbers of cases.
  - Care needed e.g. to estimate skill of 51 member ensemble based on past performance of 25 member ensemble
  - For regions of high signal/noise, SEAS5 gives adequate skill estimates
  - For regions of low signal/noise (eg <= 0.5), need hundreds of years, 36 years available is not enough

Skill can vary a lot with season ……

MAM

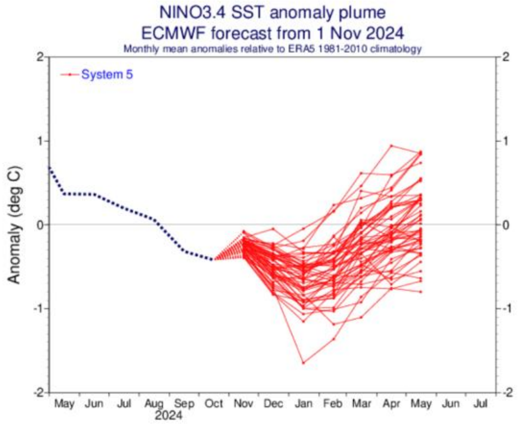
JJA

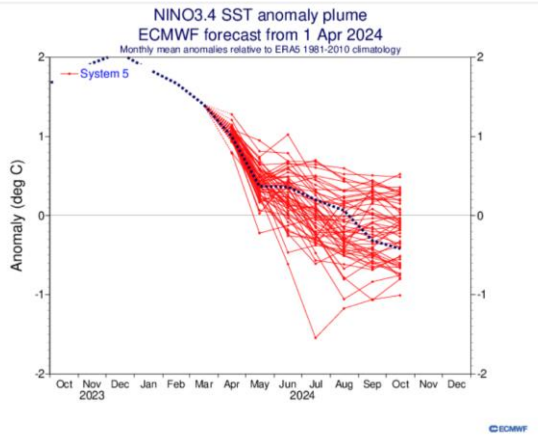


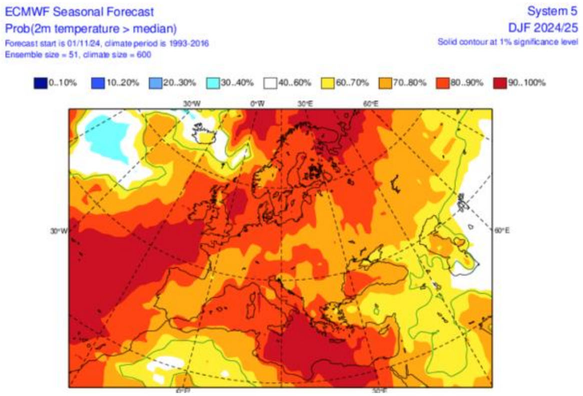
SON

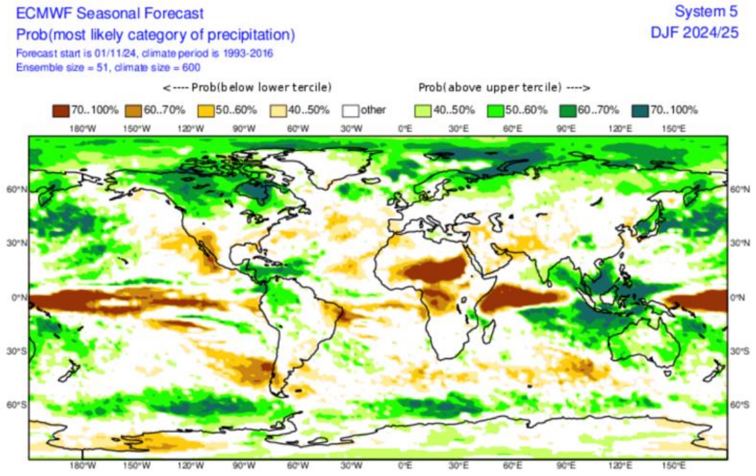
DJF

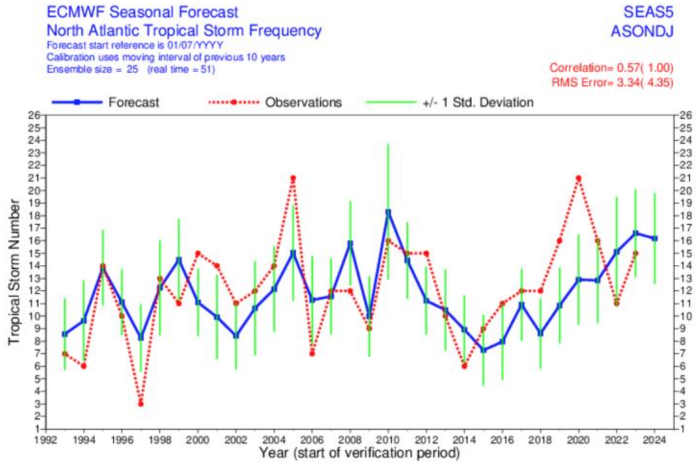
Operational production

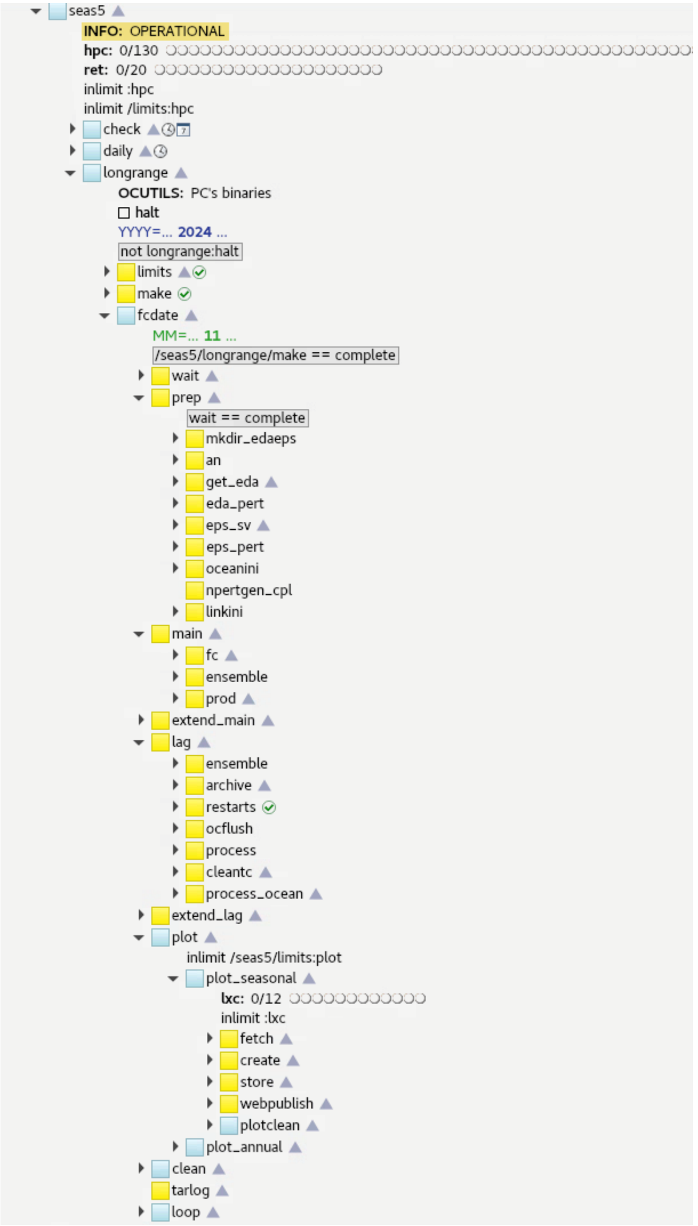






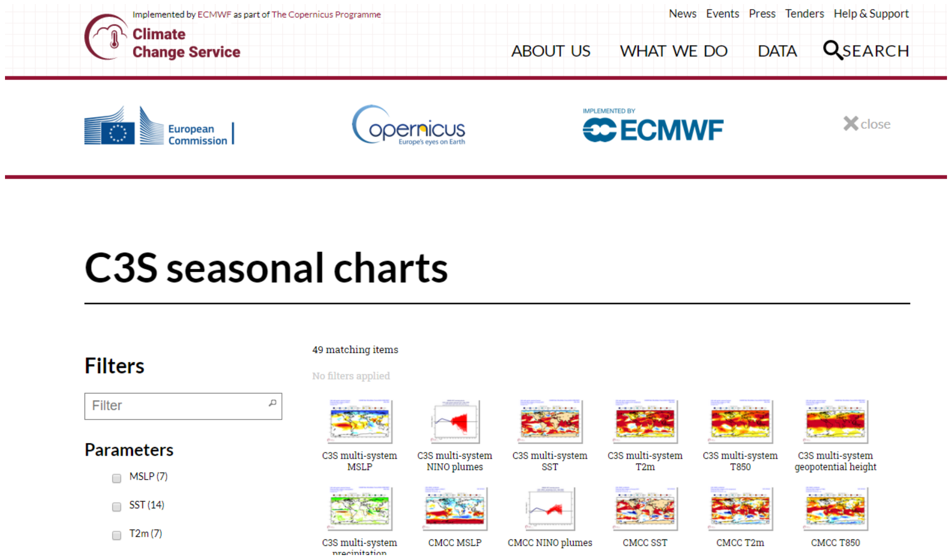






Alternative approach to model errors: multi-model

- First operational system: EUROSIP
- New incarnation: C3S from COPERNICUS
- More comments in tomorrow's lecture on calibration



Summary – operational aspects

- ECMWF seasonal forecasting is largely **seamless** with medium/extended range configurations
  - A very small number of adaptions important for longer timescales
  - Aim is to incorporate these into medium-range configuration to have a completely unified system
- Seasonal forecast configuration includes extensive re-forecast set
  - Dominates cost of system, only updated at intervals of several years
  - Allows many types of calibration and estimation of skill
- Seasonal forecast product set includes large range of graphical products
  - Fundamental rule is that all products should be provided alongside estimates of skill and/or reliability
- Multi-model seasonal forecasts are provided by C3S
  - These are considered to be better than any single model, and should always be consulted

Summary – scientific considerations

- Forecasting models are fairly realistic in many ways, but remaining errors are enough to substantially impact forecast skill and reliability, even after calibration
- Creating consistent initial conditions for past and present is a challenge, due in particular to the lack of observational data in the past. Observing systems are better now, but still need some improvements.
- Limited predictability and limited past data prevent us being sure about the skill levels of today's forecast systems, and assessment of improvements in forecast skill is difficult.
- Multi-model ensembles are helpful, **but** they only partially span the space of model errors.
- In the end, the only way to achieve high reliability is to build trustworthy models

References and further reading

SEAS5 forecasts on www.ecmwf.int/en/forecasts/charts and https://climate.copernicus.eu/seasonal-forecasts

ECMWF Seasonal Forecast User Guide

SPECS fact sheets http://www.specs-fp7.eu/Fact%20sheets on seasonal forecasting

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