The ECMWF ensemble prediction systems: from the medium-range to the seasonal scale

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Introduction to ECMWF forecasts

- High-resolution (16 km, 137 levels) medium-range forecast up to day 10, at 00 and 12 UTC
- 4D-var high-res. analysis and 25-member ensemble of data assimilations at reduced resolution
- 51-member ensemble fc, atm. res. 32 km up to day 10 (leg A) and 64 km to day 15 (leg B), 91 levels, with coupled IFS-NEMO model, at 00 and 12 UTC
- Monthly fc. made by extending the ENS leg B to 32 days at 00 UTC on Monday and Thursday
- 51-member seasonal forecasts started on the 1st day of each month, up to 7 months or 13 months (from Feb, May, Aug, Nov) with IFS (80 km L91) and NEMO 1-deg

ECMWF coupled ensemble systems (1)

System	atmosphere model cycle	atmosphere spectral truncation	atmosphere vertical levels	ocean model	ocean horizontal res, equatorial refinement	ocean vertical levels
ENS Day 1-15/32 (before Nov. 2013)	IFS cy 38r2	T639 (d 0-10), T319	62 levels, top = 5 hPa	NEMO v 3.0/3.1	1 degree, ~ 0.3 deg. Lat	42 levels
ENS Day 1-15/32 (from Nov. 2013)	IFS cy 40r1	T639 (d 0-10), T319	91 levels, top = 1 Pa	NEMO v 3.4	1 degree, ~ 0.3 deg. Lat	42 levels
System 4 Month 1-7/13	IFS cy 36r4	T255	91 levels, top = 1 Pa	NEMO v 3.0/3.1	1 degree, ~ 0.3 deg. Lat	42 levels
MINERVA Month 1-7	IFS cy 38r1	T319 / T639 / T1279	91 levels, top = 1 Pa	NEMO v 3.0/3.1	1 degree, ~ 0.3 deg. Lat	42 levels

ECMWF coupled ensemble systems (2)

System	coupler	time range of ocean-atmosphere coupling	coupling frequency	unperturbed initial cond. for re-forecasts	atmospheric perturbations	ocean perturbations	stochastic model perturbations
ENS Day 1-15/32 (before Nov. 2013)	OASIS-3	from day 10	3 hours	ERA-Interim + ORA-S4	SV, EDA from current or recent date	generated by ENS member fluxes during day 1 to 10	3-timescale SPPT + KE backsc.
ENS Day 1-15/32 (from Nov. 2013)	sequential, single exec. code	from start	3 hours	ERA-Interim + ORA-S4	SV, EDA from current or recent date	5 ocean analyses	3-timescale SPPT + KE backsc.
System 4 Month 1-7/13	OASIS-3	from start	3 hours	ERA-Interim + ORA-S4	SV	5 ocean analyses + SST perturb.	3-timescale SPPT + KE backsc.
MINERVA Month 1-7	OASIS-3	from start	3 hours	ERA-Interim + ORA-S4	SV, EDA from 2011 dates	5 ocean analyses + SST perturb.	3-timescale SPPT + KE backsc.

ORA-S4 : Ocean Re-Analysis for ECMWF System-4

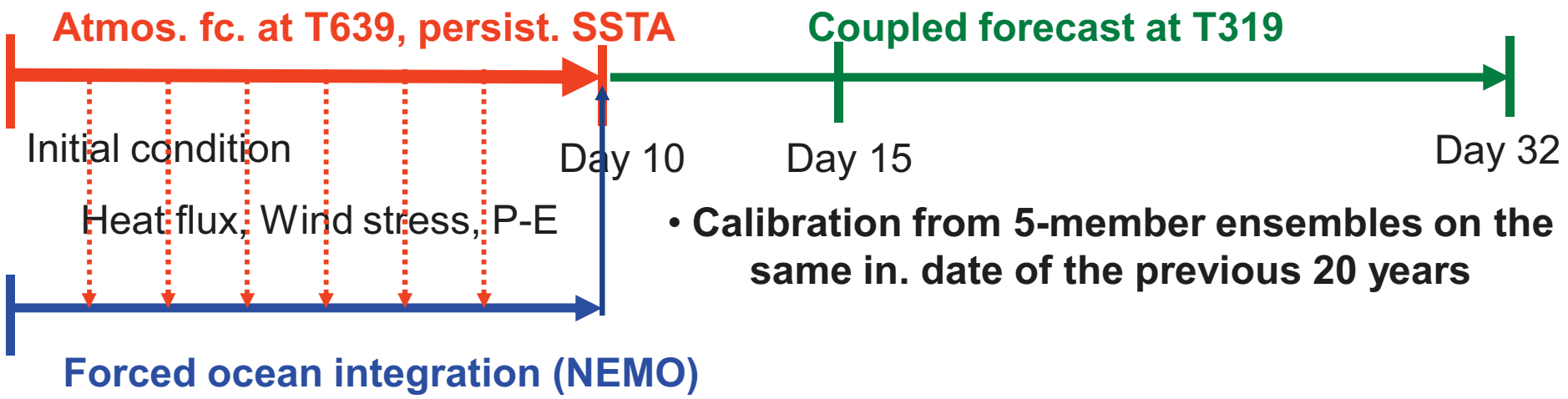
EDA : Ensemble of Data Assimilations (low-res 4D-var)

SV : Singular Vectors of 48-hour linear propagator

SPPT : Stochastic Perturbation of Physical Tendencies

Unified ENS/monthly forecasts at ECMWF

Previous ENS/monthly system: 15 days twice daily, 32 days twice a week (Mon + Thu)



- **Calibration from 5-member ensembles on the same in. date of the previous 20 years**

ENS/monthly system in Cycle 40r1 (operational from 19 Nov. 2013)

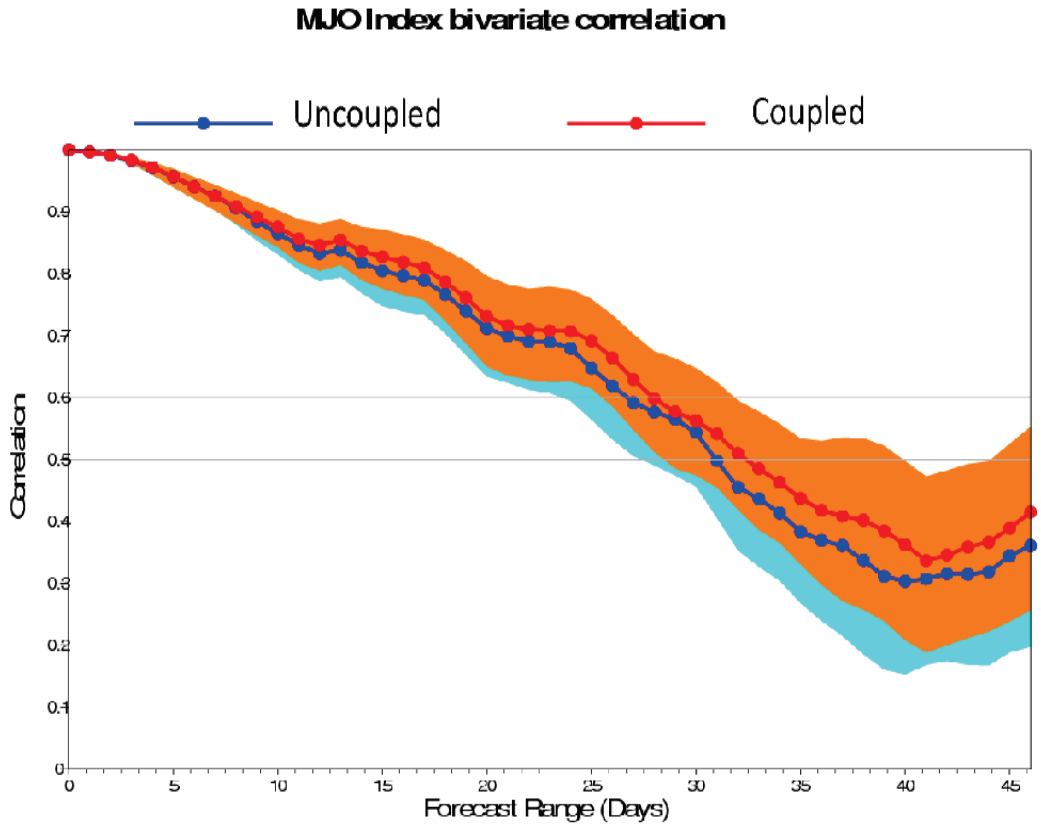
Tendency coupling in ENS (day 1-10)

- Motivation:
  - Start the ENS with the same high-resolution observed SST used for the HRES forecast (UKMO OSTIA SST)
  - Avoid SST degradation due to low-resolution ocean IC in the early part of the forecast (eg, impact on T_2m in coastal regions)
  - Get smooth transition to full coupling at fc. day 10

- Tendency coupling:
  - SST(t) = SST_obs(t0) + [SST_nemo(t) – SST_nemo(t0)] =
    SST_nemo(t) + [SST_obs(t0) – SST_nemo(t0)]

- Transition from day 5 to day 10:
  - SST(t) = SST_nemo(t) + w(t) [SST_nemo(t0) – SST_obs(t0)]
  - w(t) = 1 until day 5, decreases linearly to 0 at day 10

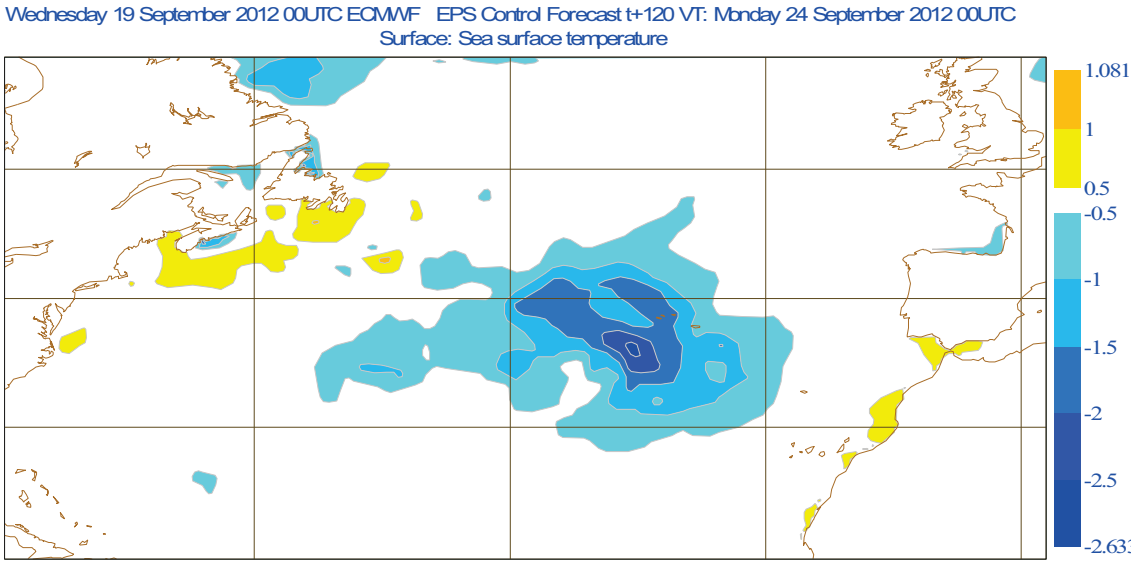
Impact of coupling from day 0 on MJO forecast



- Correlation of bi-variate MJO index between ensemble mean and ERA, from a set of ENS experiments with coupling from day 0 (red) and with operational configuration (blue). The shaded bands show the variability of scores (+/- 1 stand.dev.) among individual cases.

Coupling from day 0: tropical cyclones

Hurricane Nadine – 19/09/2012
SST day 5 – day0



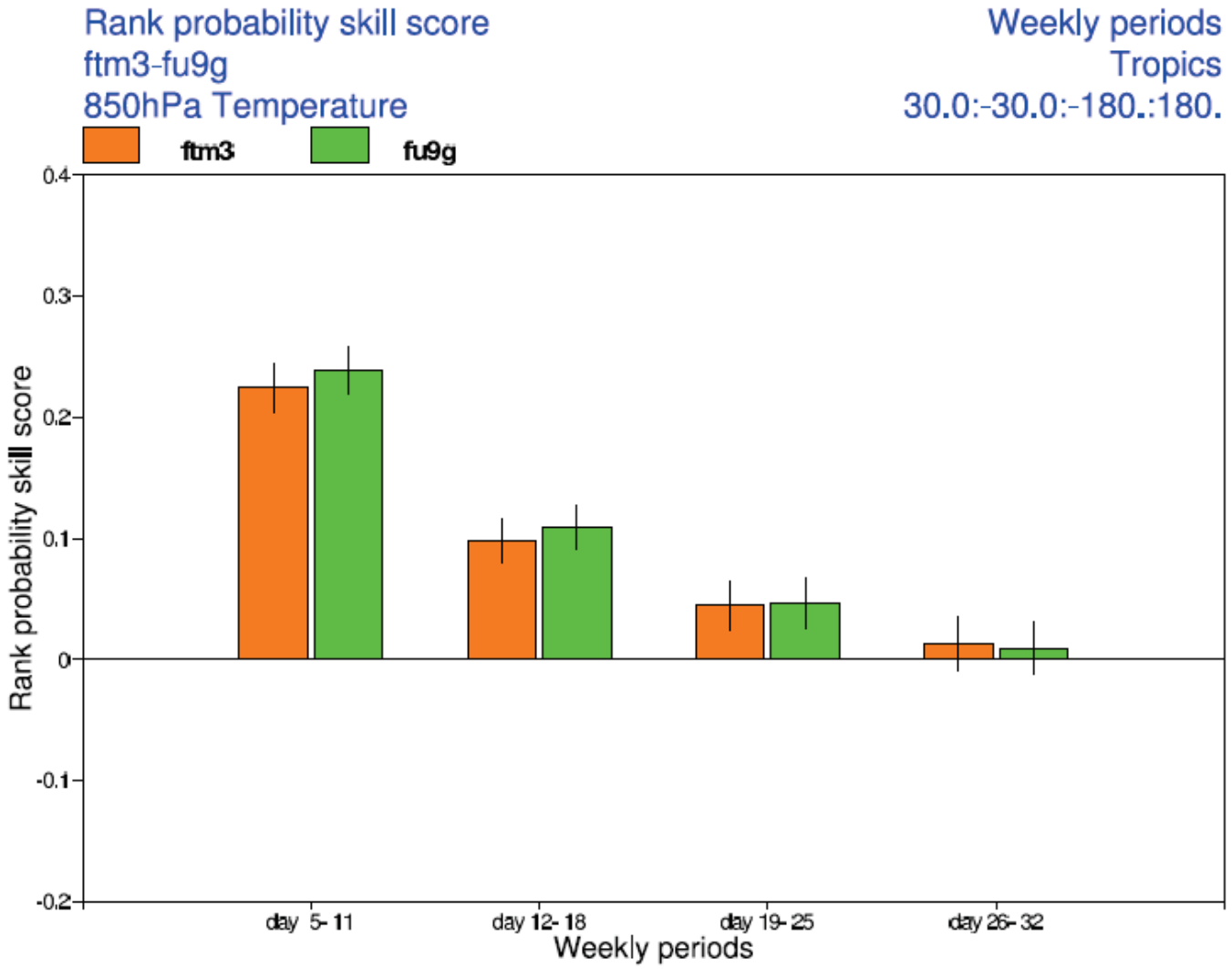
Maximum 10-m Wind velocity (m/s)

	MEAN	STD
OBS	38	
Oper	30.9	3.3
Coupled Exp	26.5	1.7

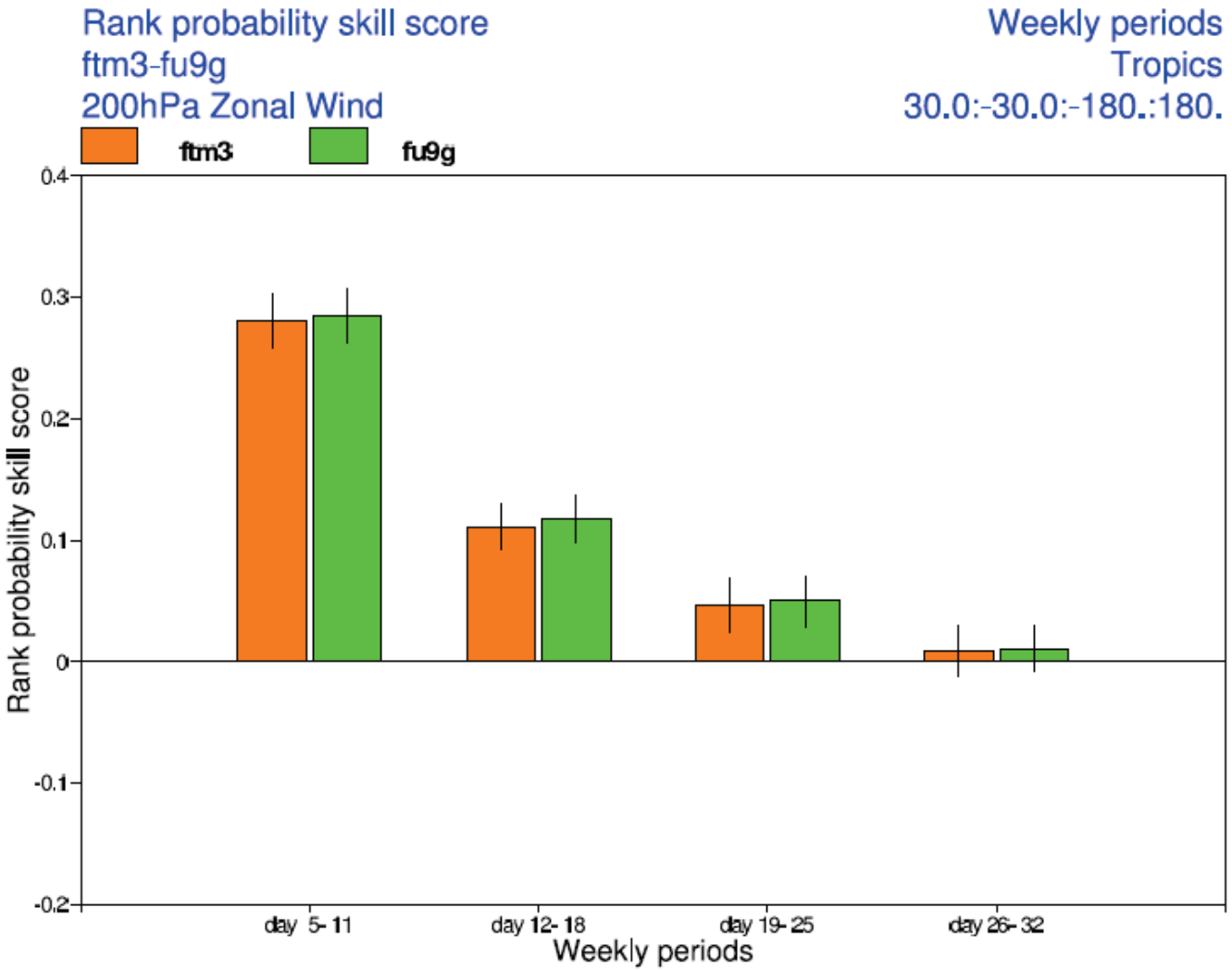
MSLP

	MEAN	STD
OBS	978	
Oper	971	9
Coupled Exp	979	4.6

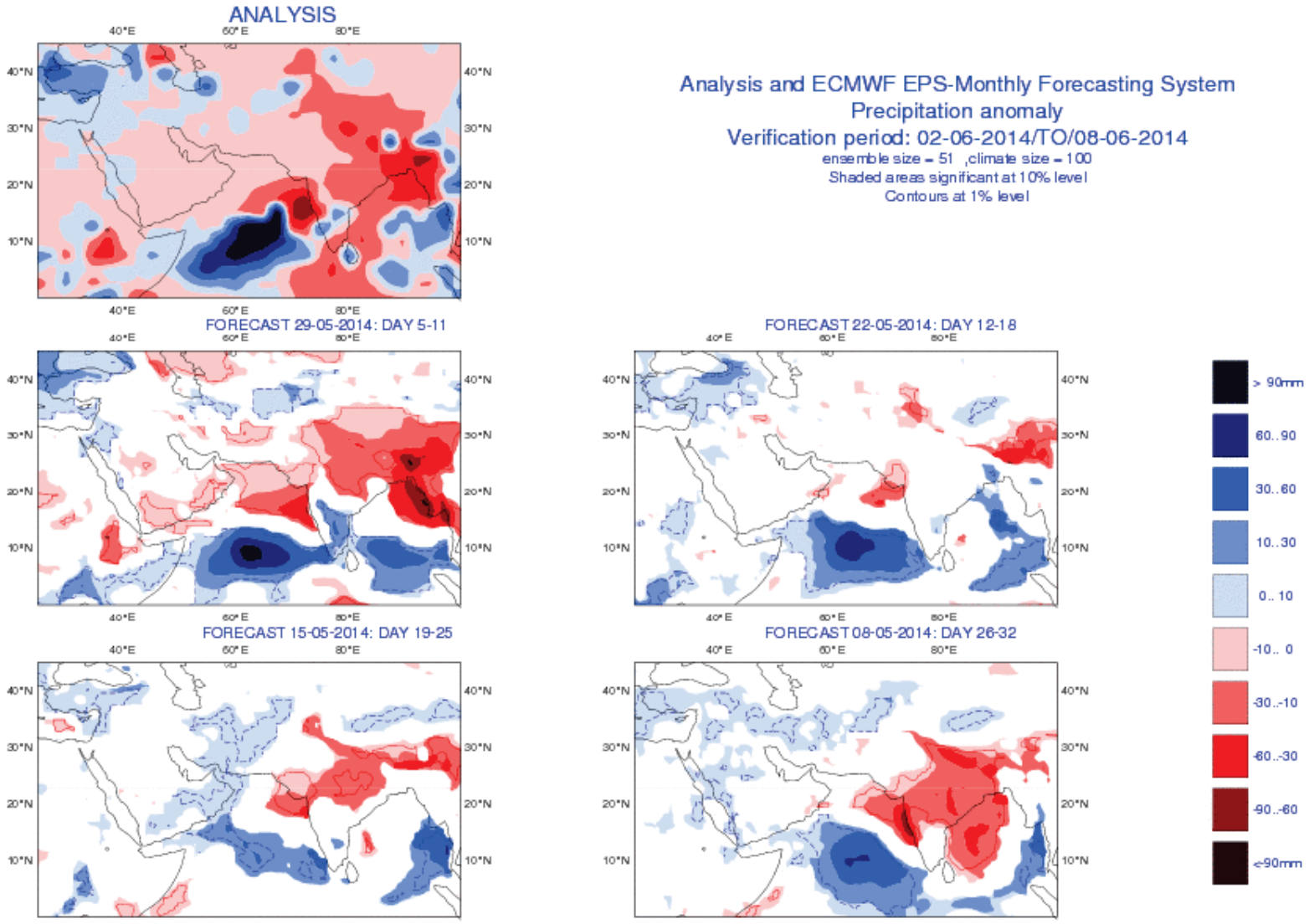
Coupling from day 0: weekly-mean scores



Coupling from day 0: weekly-mean scores



Monthly forecast products: ensemble-mean anomalies



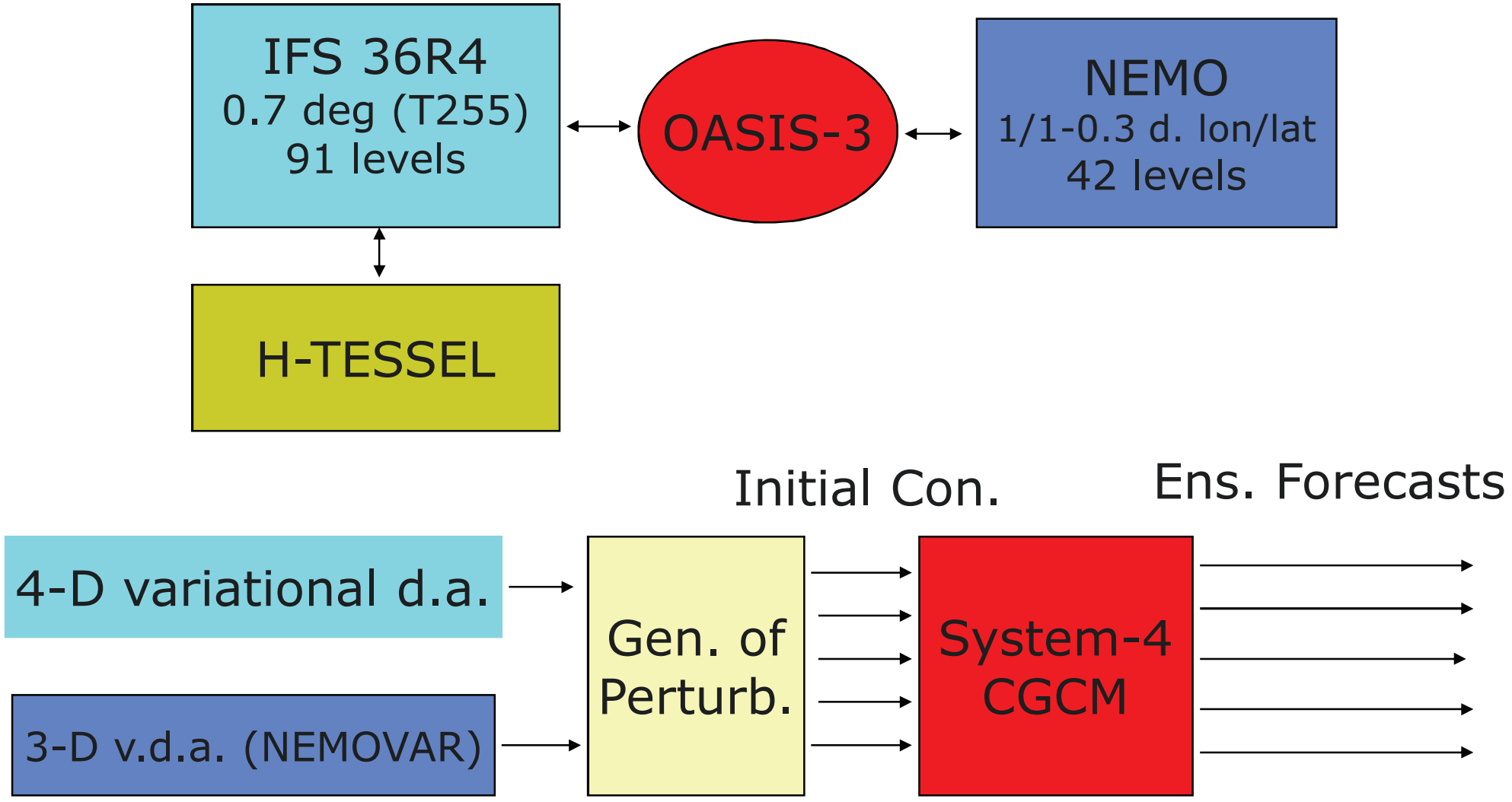
Operational seasonal forecasts at ECMWF

- Real time forecasts since 1997
  - System 1 initially made public as "experimental" in Dec 1997
  - System 2 started running in August 2001, released in early 2002
  - System 3 started running in Sept 2006, operational in March 2007
  - System 4 started running in July 2011, operational in November 2011

- Burst mode ensemble forecast
  - Initial conditions are valid for 0Z on the 1st of a month
  - Forecasts are usually complete by late on the 2nd.
  - Forecast and product release date is 12Z on the 8th.

- Range of operational products
  - Moderately extensive set of graphical products on web
  - Raw data in MARS
  - Formal dissemination of real time forecast data

The ECMWF Seasonal fc. system (Sys-4)



ECMWF seasonal fc. System 4: main features

- **IFS model cycle: 36r4** (op. Nov. 2010-May 2011), **T255-L91**
- **Ocean model : NEMO (v. 3.0 + 3.1 coupling interface)**
  - ORCA-1 configuration (~1-deg. resol., ~0.3 lat. near the equator)
  - 42 vertical levels, 20 levels with z < 300 m
- **Variational ocean data assimilation (NEMOVAR)**
  - FGAT 3D-var, re-analysis (ORA-S4) and near-real-time system
- **Operational forecasts**
  - 51-member ensemble from 1st day of the month, released on the 8th
  - 7-month integration
  - 13-month extension (with 15 ens. members) from 1st Feb/May/Aug/Nov
- **Re-forecast set**
  - 30 years, start dates from 1 Jan 1981 to 1 Dec 2010
  - 15-member ensembles, 7-month integrations
  - 13-month extension from 1st Feb/May/Aug/Nov
  - Extended set: 7-month, 51 members from 1st Feb/May/Aug/Nov

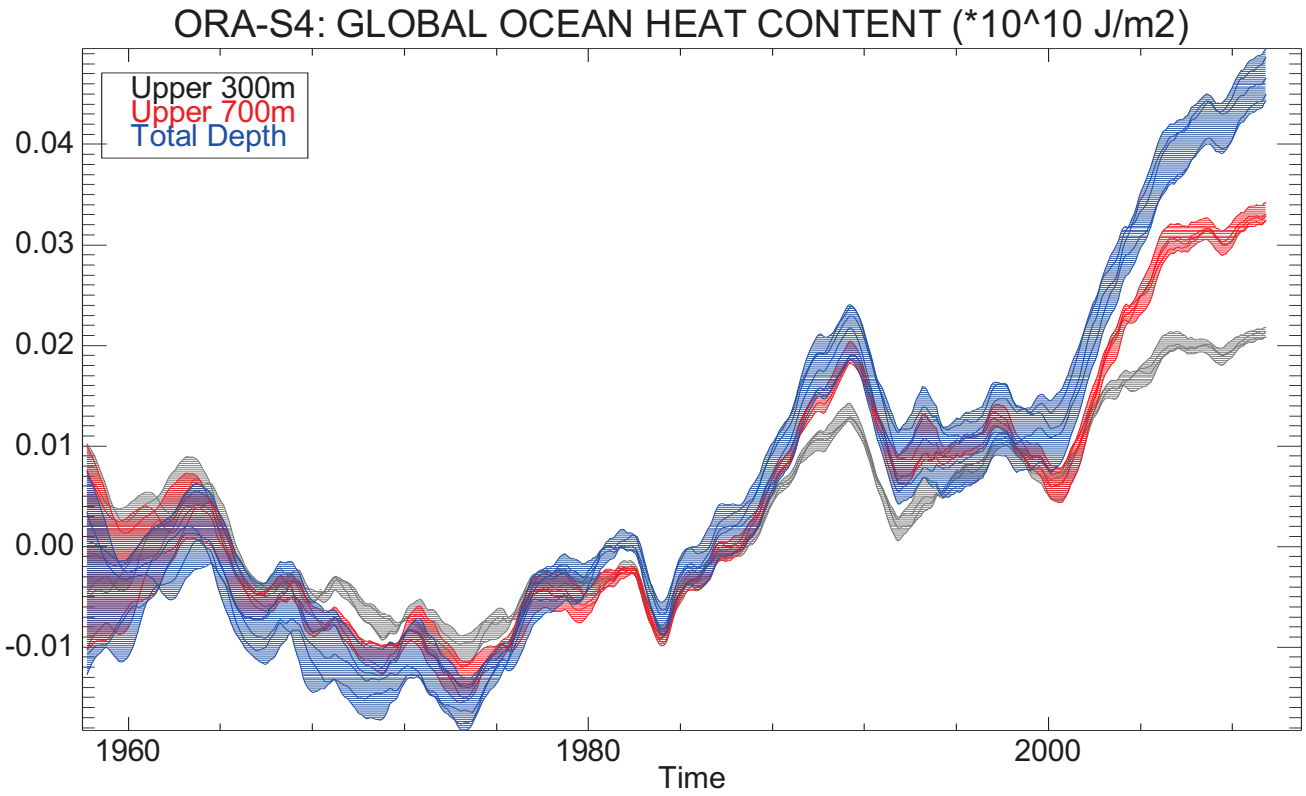
Removing systematic errors in seasonal forecasts

- Model drift is typically comparable to signal
  - Both SST and atmosphere fields
- Forecasts are made *relative* to past model integrations
  - Model climate estimated from 30 years of forecasts (1981-2010), all of which use a 15 member ensemble. Thus the climate has 450 members.
  - Model climate has both a mean and a distribution, allowing us to estimate e.g. tercile boundaries.
  - Model climate is a function of start date and forecast lead time.
- Implicit assumption of linearity
  - We implicitly assume that a shift in the model forecast relative to the model climate corresponds to the expected shift in a true forecast relative to the true climate, despite differences between model and true climate.
  - Most of the time, assumption seems to work pretty well. But not always.

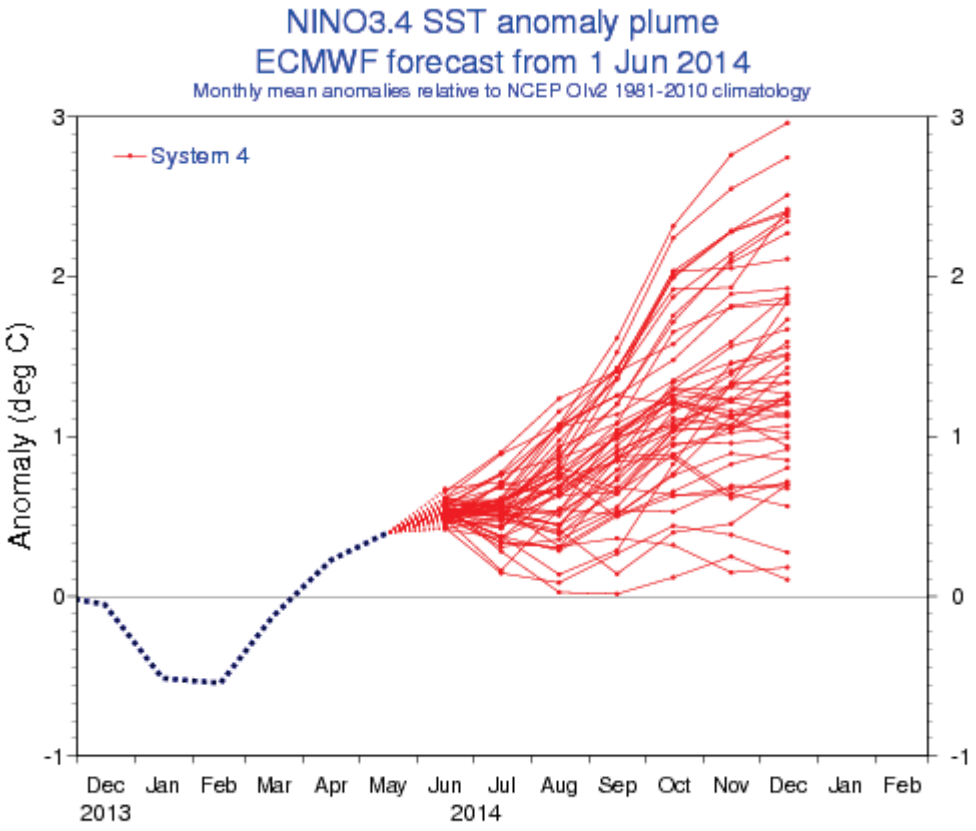
The System-4 Ocean Re-Analysis (ORA-S4)

Variational ocean data assimilation (NEMOVAR)

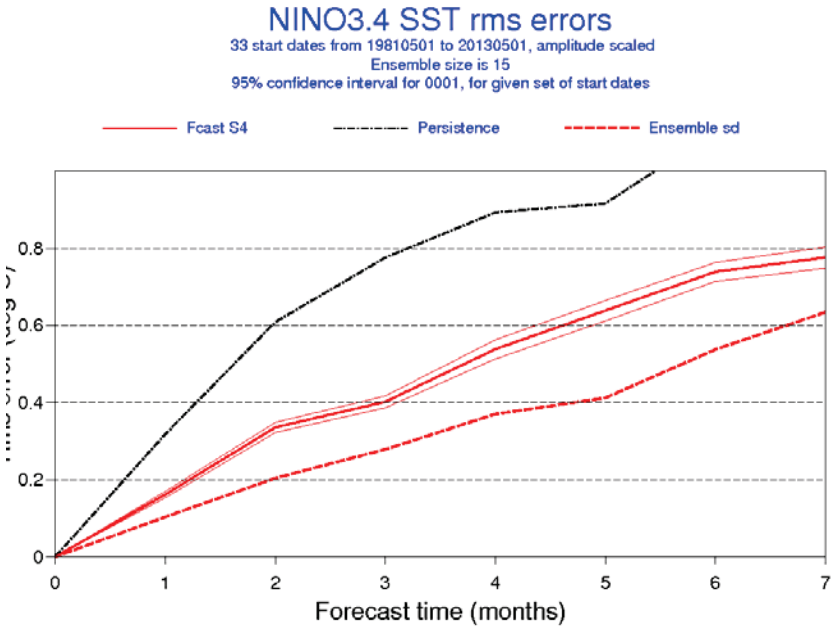
- **3-D var FGAT with inner and outer loop**
- **Collaboration with CERFACS, UK Met Office, INRIA**
- **Re-analysis (ORA-S4) and real-time system**



Products: ENSO indices



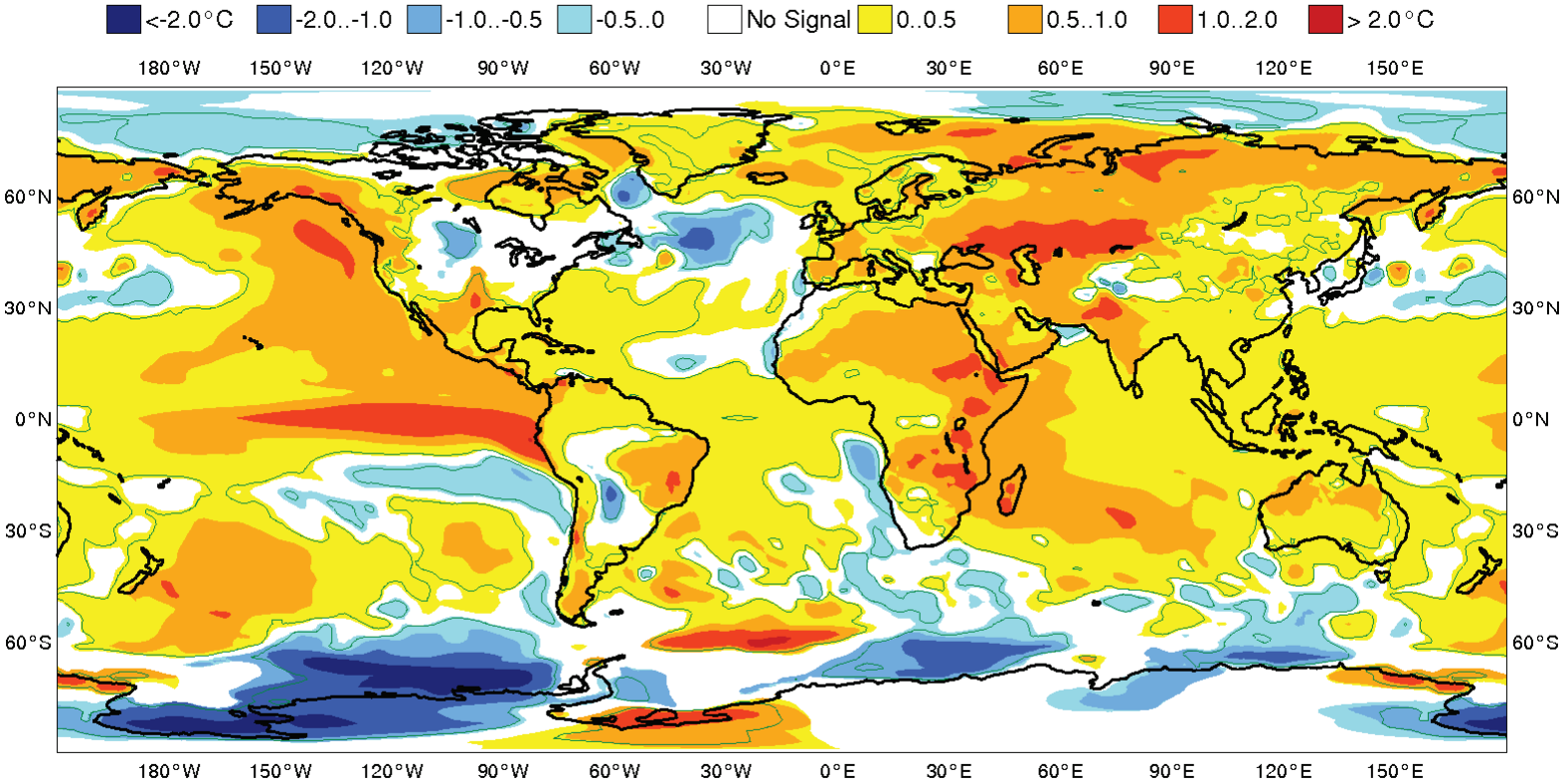
Past performance



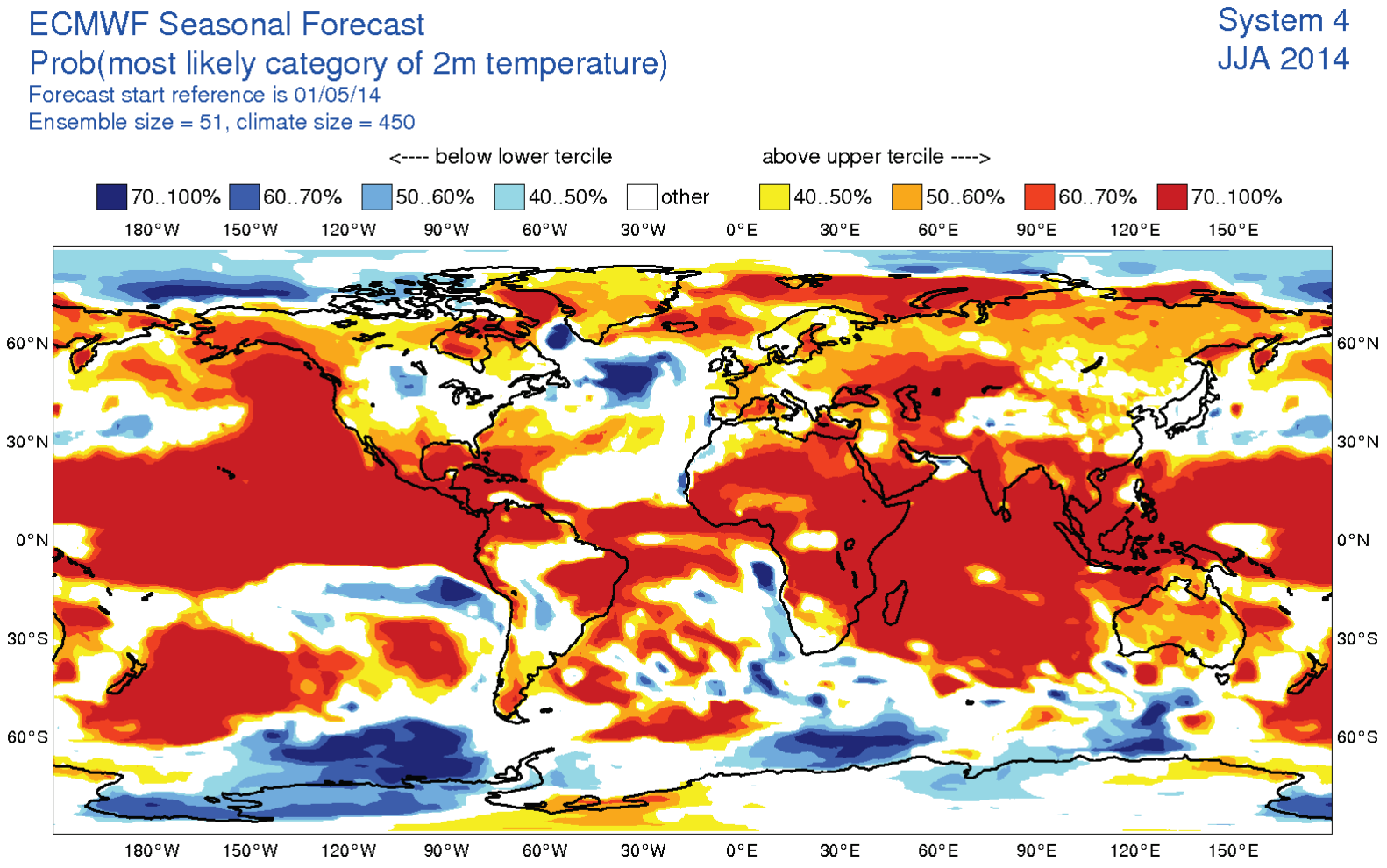
Products: Ensemble mean anomaly

ECMWF Seasonal Forecast
Mean 2m temperature anomaly
Forecast start reference is 01/05/14
Ensemble size = 51, climate size = 450

System 4
JJA 2014
Shaded areas significant at 10% level
Solid contour at 1% level



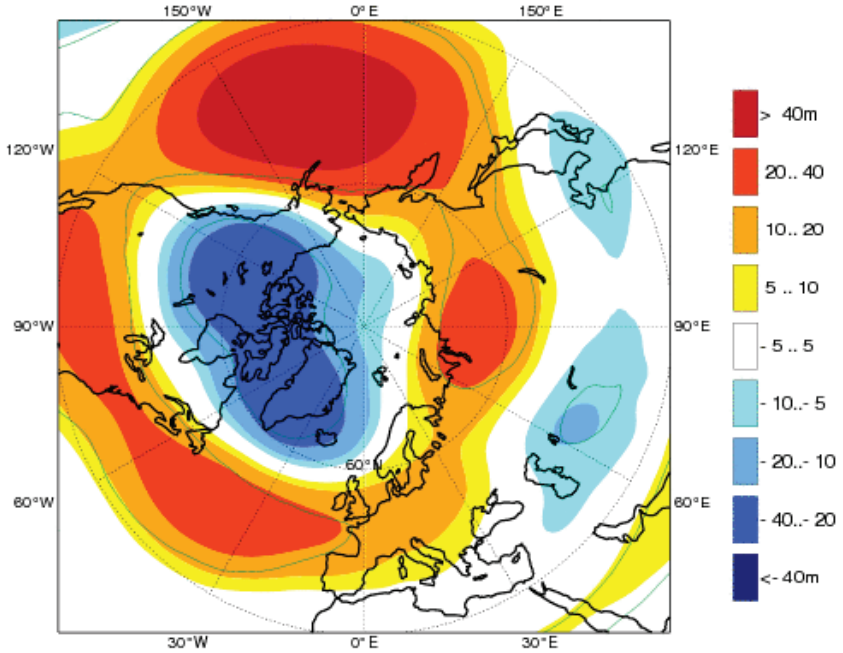
Products: Probability of tercile categories



Examples of other operational plots

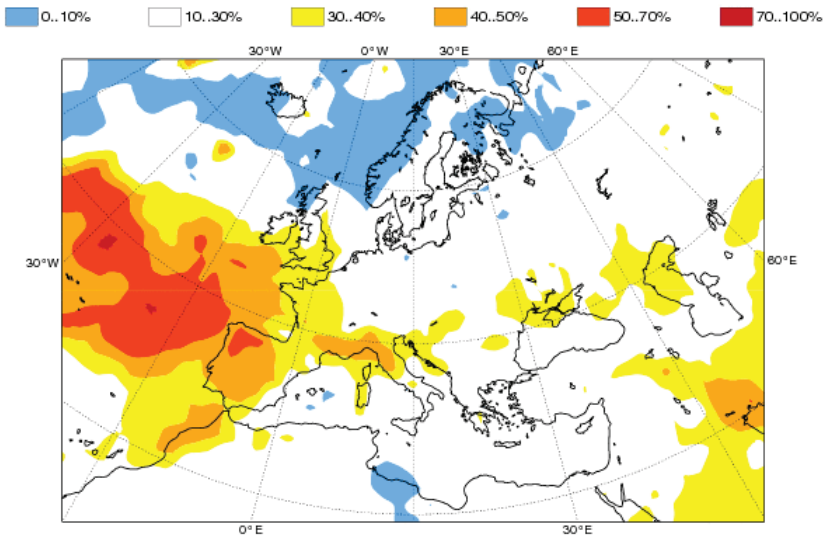
ECMWF Seasonal Forecast
Mean Z500 anomaly
Forecast start reference is 01/11/11
Ensemble size = 51, climate size = 450

System 4
DJF 2011/12
Solid contour at 1% significance level



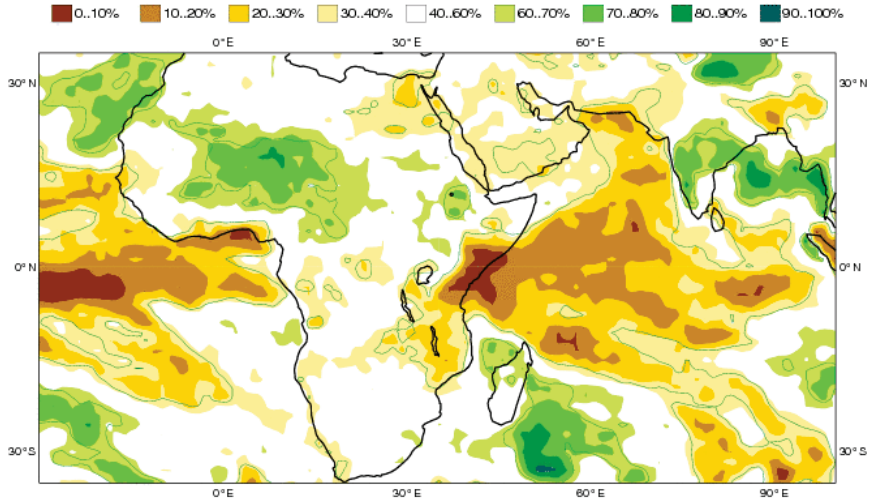
ECMWF Seasonal Forecast
Prob(lowest 20% of climatology) - precipitation
Forecast start reference is 01/12/11
Ensemble size = 51, climate size = 450

System 4
JFM 2012

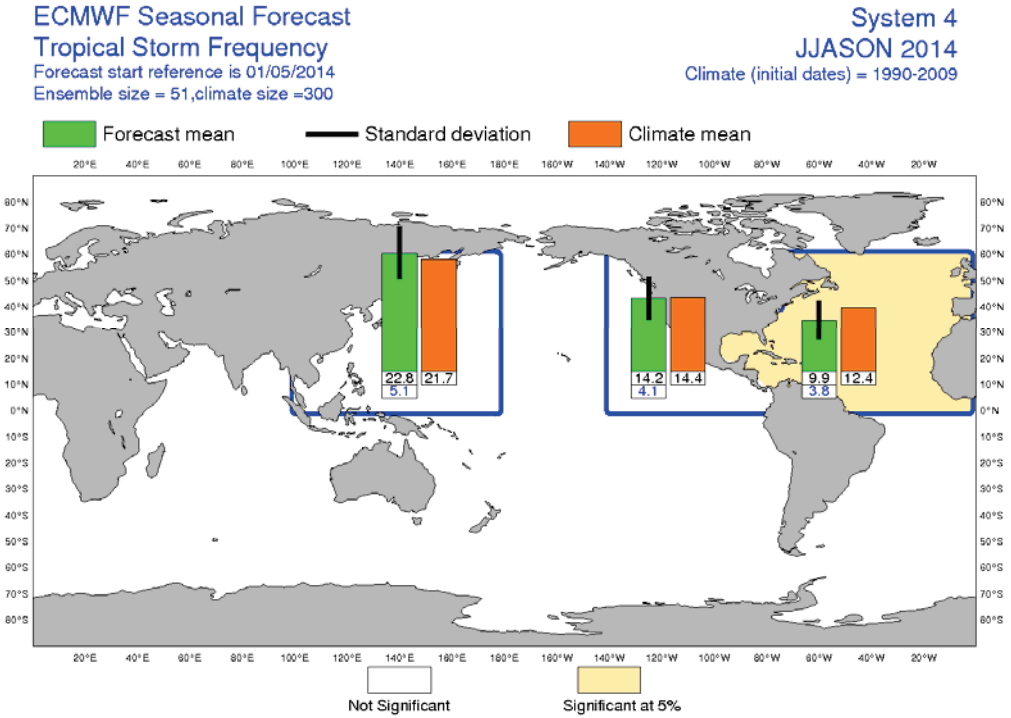


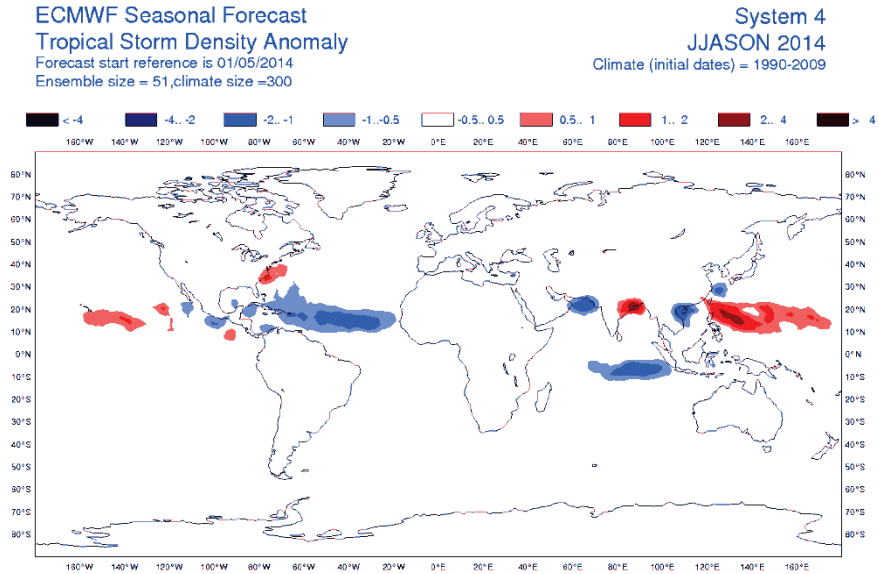
ECMWF Seasonal Forecast
Prob(precipitation > median)
Forecast start reference is 01/05/12
Ensemble size = 51, climate size = 450

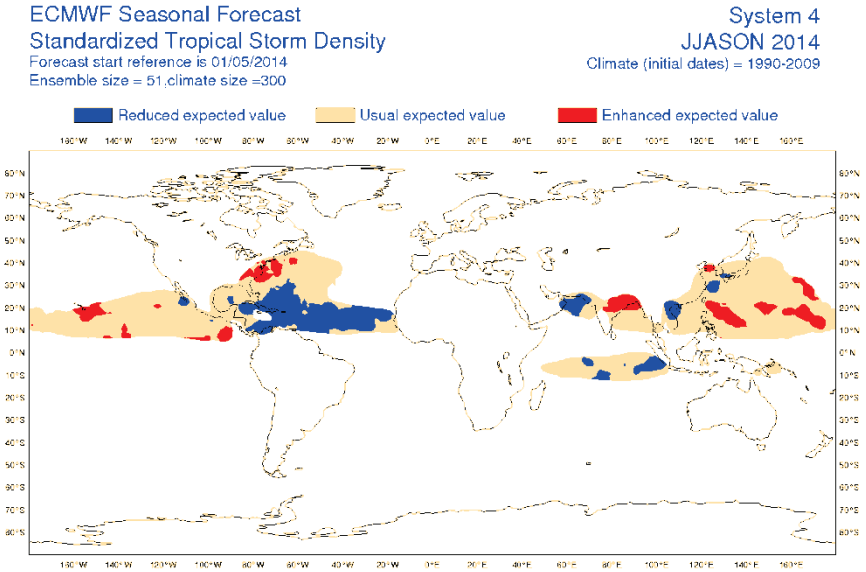
System 4
JJA 2012
Solid contour at 1% significance level



Tropical storm forecasts

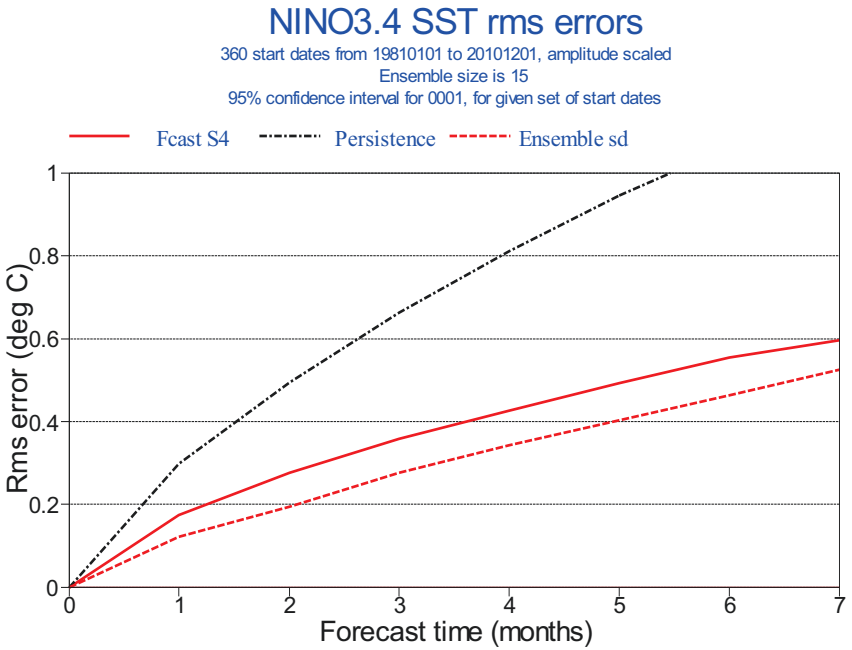


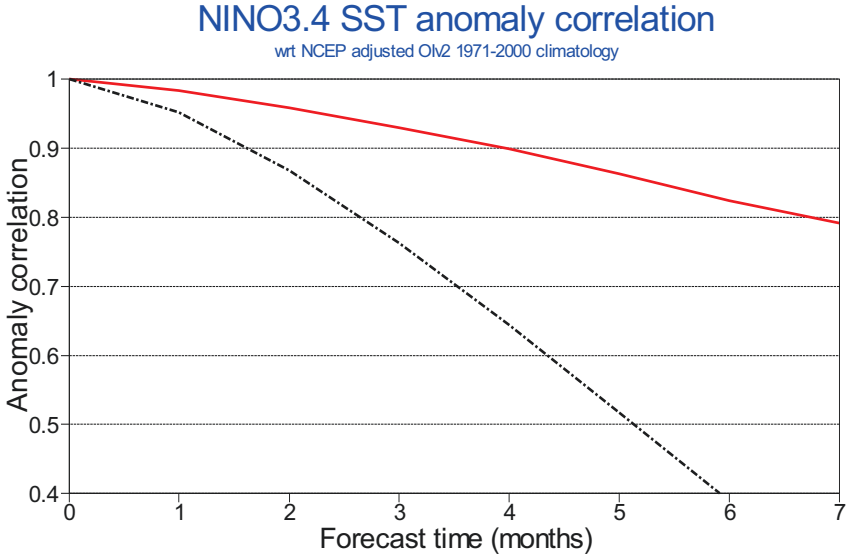




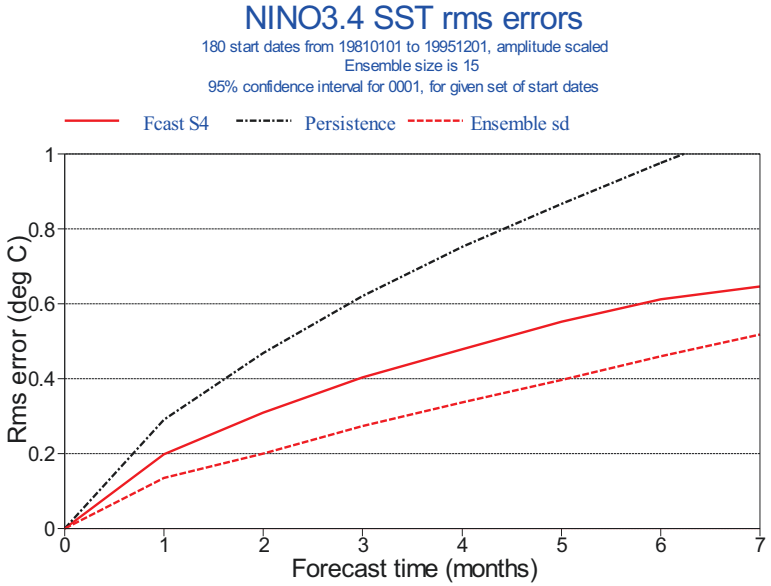
SST forecast performance

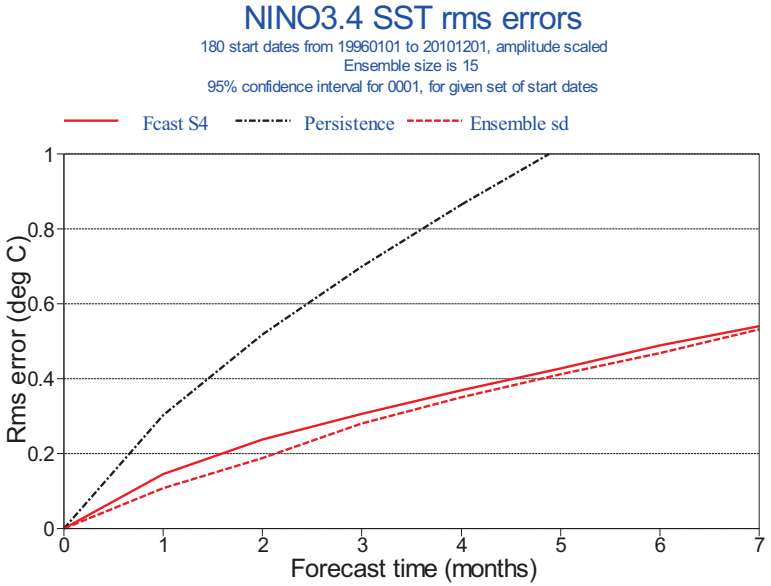
Actual rms errors > model estimate of "perfect model" errors





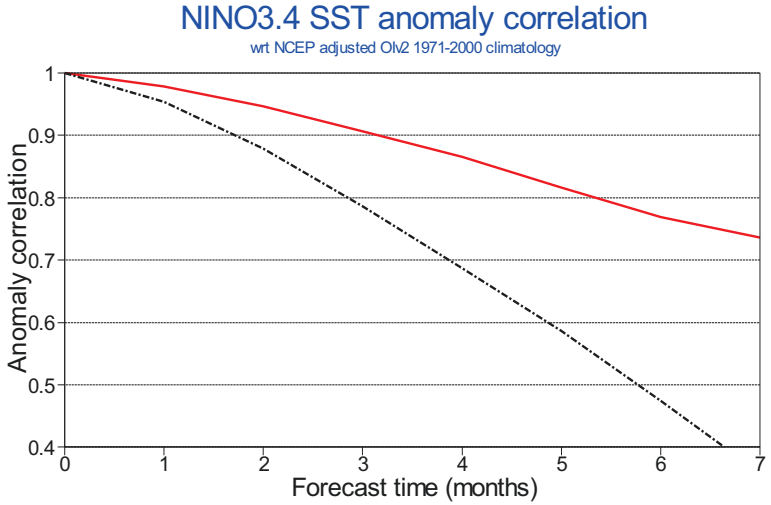
More recent SST forecasts are better ....

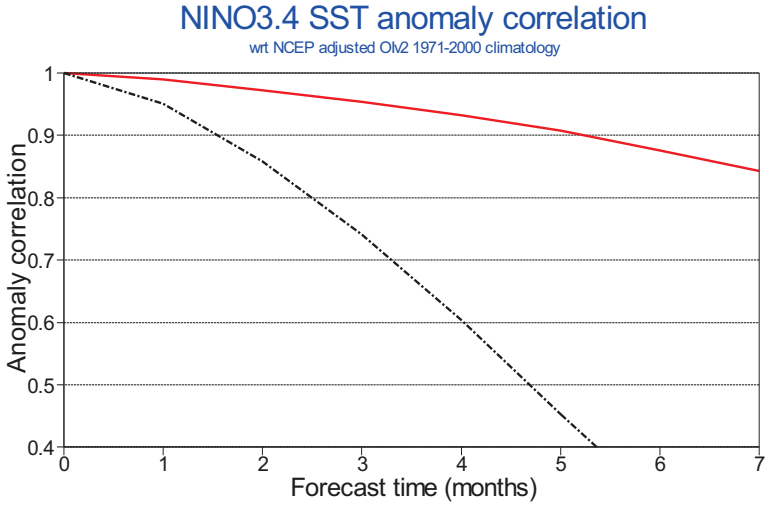




1981-1995

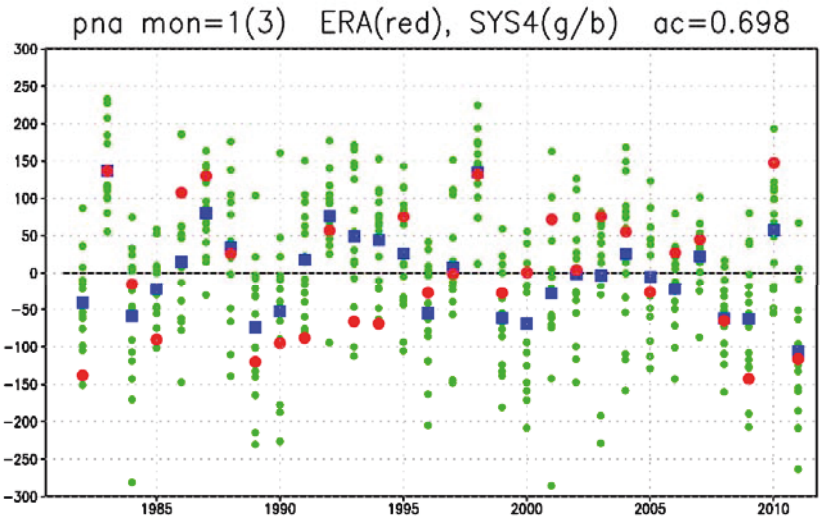
1996-2010

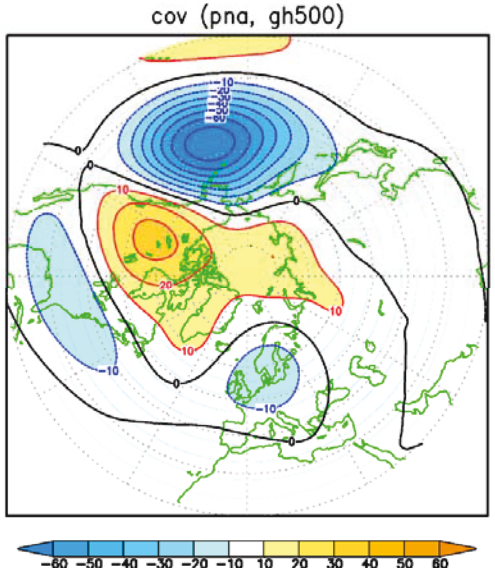




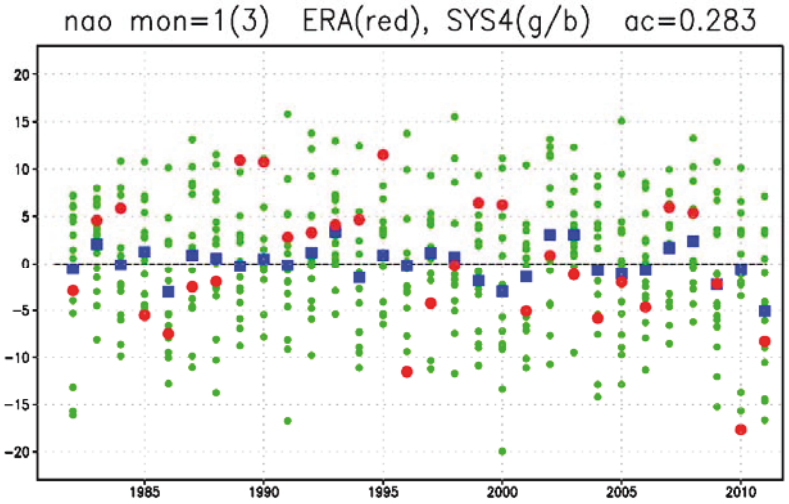
Predictability of teleconnections in Sys4: PNA, NAO (DJF)

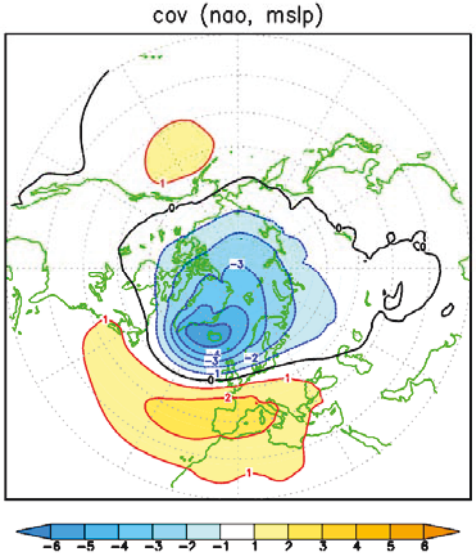
PNA





NAO

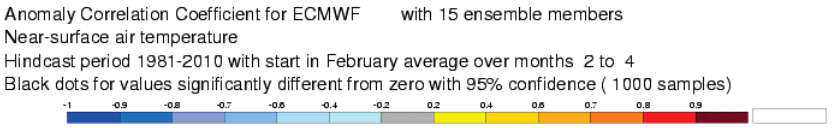




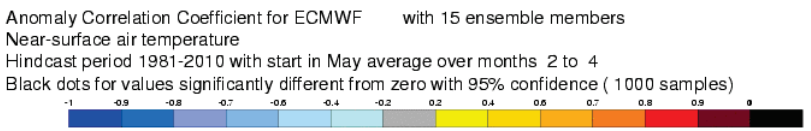
How good are the forecasts in specific locations?

Deterministic skill: ACC

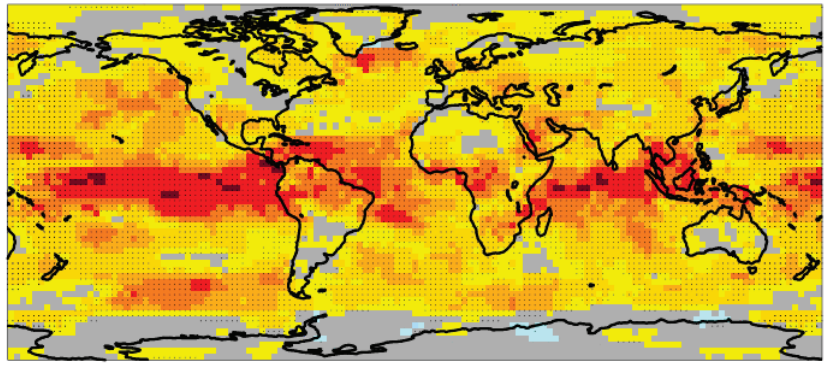
MAM

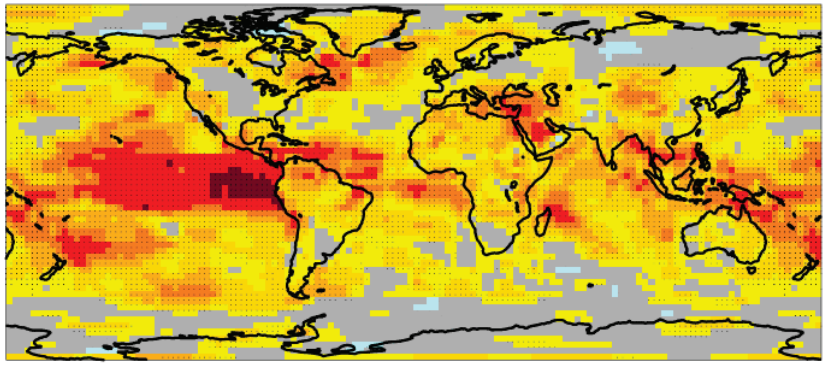


JJA

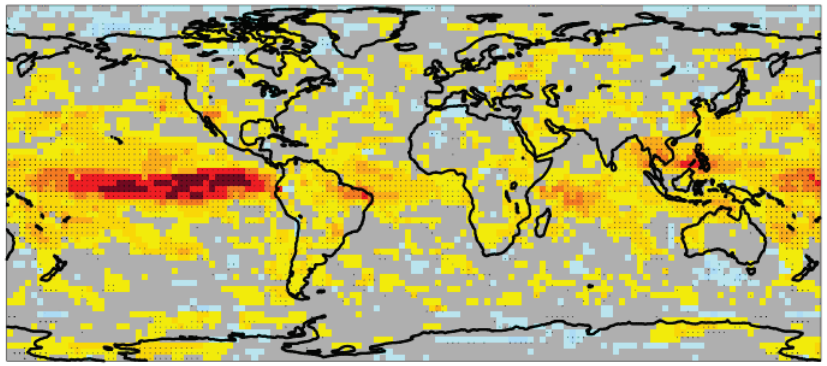


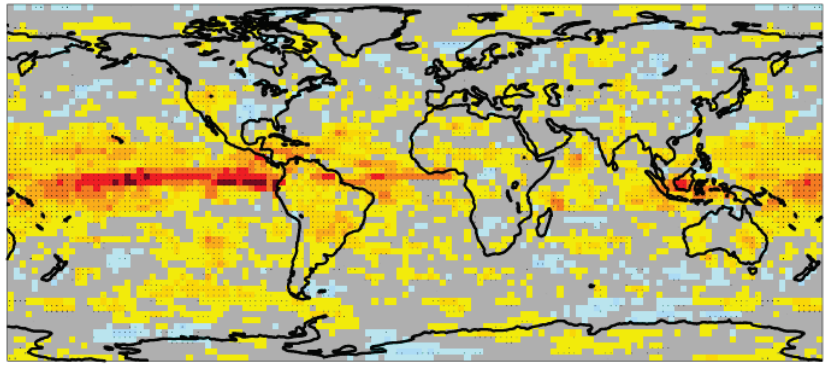
T2m





Precip





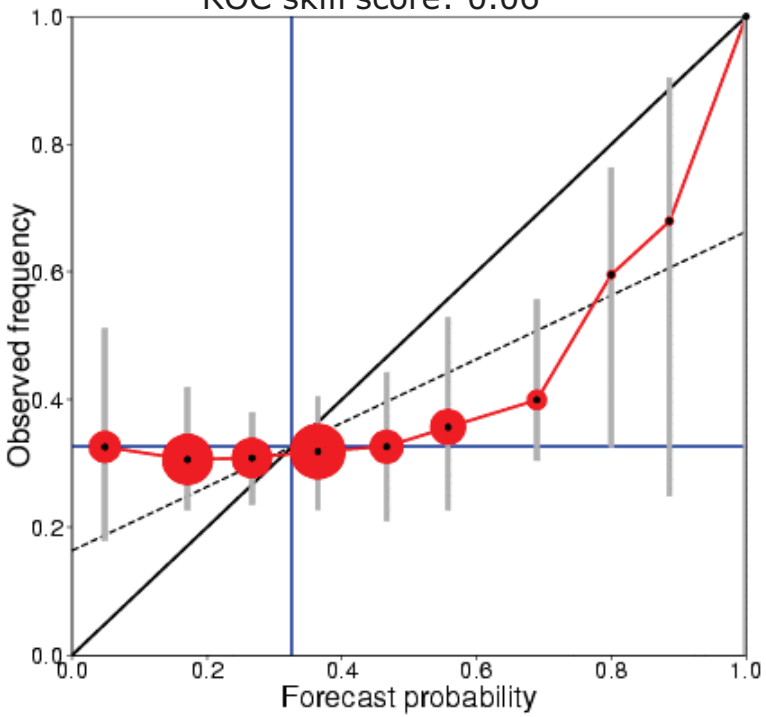
How many re-forecasts do we need?

- Re-forecasts dominate total cost of system
  - System 4: 5400 historical integrations (before implementation)
  - 612 real-time integrations (per year)
- Re-forecasts define model climate
  - We need both climate mean and the PDF, the latter needs large sample
  - One may prefer to use a "recent" period (20 years? Or less??)
  - System 2 had a 75 member "climate", S3 had 275, S4 has 450.
- 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 15 member ensemble
  - For regions of high signal/noise, System 4 gives adequate skill estimates
  - For regions of low signal/noise (eg <= 0.5), need hundreds of years

Probabilistic scores for Europe: DJF

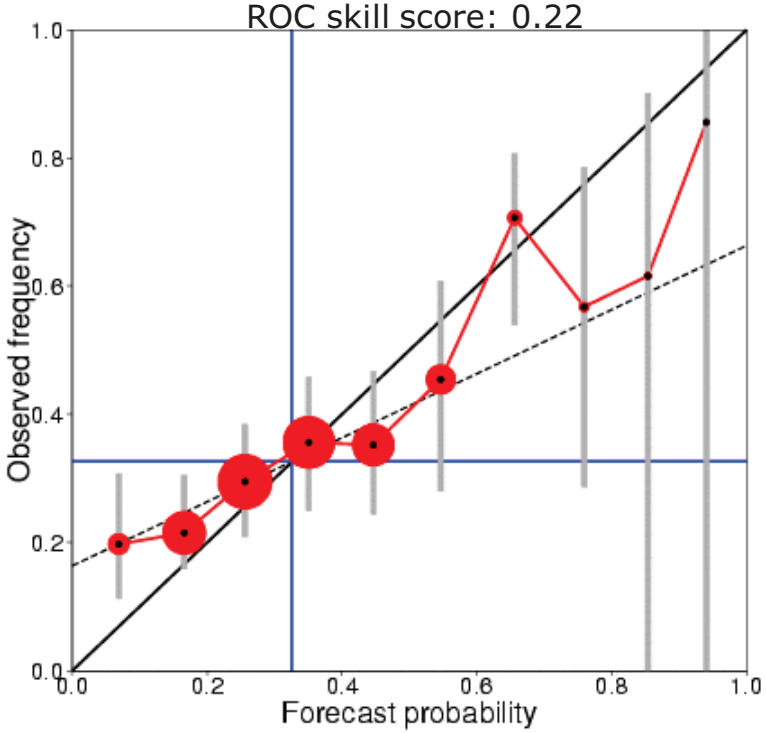
15 members

DJF Europe T2m>upper tercile
Re-forecasts from 1 Nov, 1981-2010
Reliability score: 0.902
ROC skill score: 0.06



51 members

DJF Europe T2m>upper tercile
Re-forecasts from 1 Nov, 1981-2010
Reliability score: 0.981
ROC skill score: 0.22



Summary

- ECMWF produces ensemble forecasts with coupled ocean-atmosphere systems ranging from a few days to 1 year.
- Monthly forecasts are run as seamless extensions of the medium-range ensemble.
- While the medium-range and monthly fc. use a frequently (typically twice a year) upgraded model version, the seasonal fc. are made with a frozen version, which allows the production of a long consistent record of re-forecasts.
- Medium-range and monthly fc benefit from the use of a coupled model since the start of the forecasts, especially for the prediction of tropical variability (MJO, tropical cyclones).
- A range of probabilistic products and verification scores from the ECMWF seasonal fc. are available to WMO users on the ECMWF web site.