Seasonal forecasting at ECMWF

L. Ferranti

The operational forecasting system

- High resolution forecast: twice per day
  16 km 91-level, to 10 days ahead

- Ensemble Prediction System (EPS): twice daily
  51 members, 30/60 km 62-level, <u>to 15 days ahead</u>

- Extended range forecasts /EPS extension: twice a week (Mon/Thursdays)
  51 members, 30/60 km 62 levels, <u>to 1 month ahead</u>

- **Long range forecasts: once a month (coupled to ocean model)**
  members, ~80 km 91 levels, <u>to 7 months ahead</u>

Sources of seasonal predictability

Atmospheric predictability arises from
slow variations in lower-boundary forcing

KNOWN TO BE IMPORTANT:

- **El Nino variability** → **biggest single signal**
- **Other tropical ocean SST** - important, but multifarious
- **Climate change** - trends in mid-latitudes
- **Local land surface conditions** - e.g. soil moisture in 2003

OTHER FACTORS:

- Mid-latitude ocean temperatures - always controversial
- Remote soil moisture/snow cover - not yet well established
- Sea ice anomalies - local effects, but remote??
- Dynamic memory of atmosphere - most likely on 1-2 months
- Stratospheric influences - downward propagation of anomalies
- Volcanic eruptions - potentially predictable if contained in initial conditions

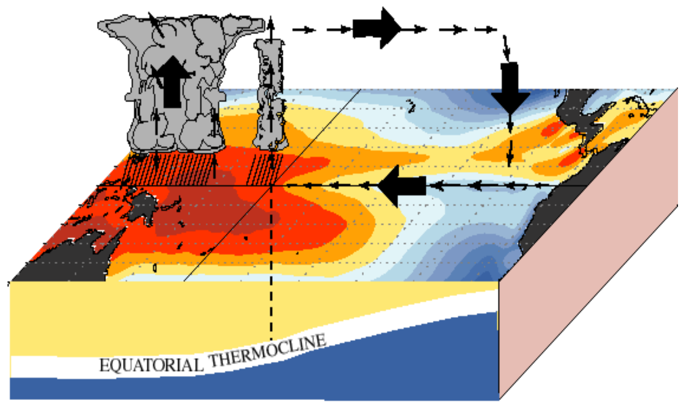
Can the weather be predicted months in advance?

- Predictions may be possible a few months in advance based on the fact that irregular weather variations have been associated with El Niño - a warming of the Pacific Ocean near the equator- and La Niña, a similar event caused by the cooling of equatorial Pacific waters.

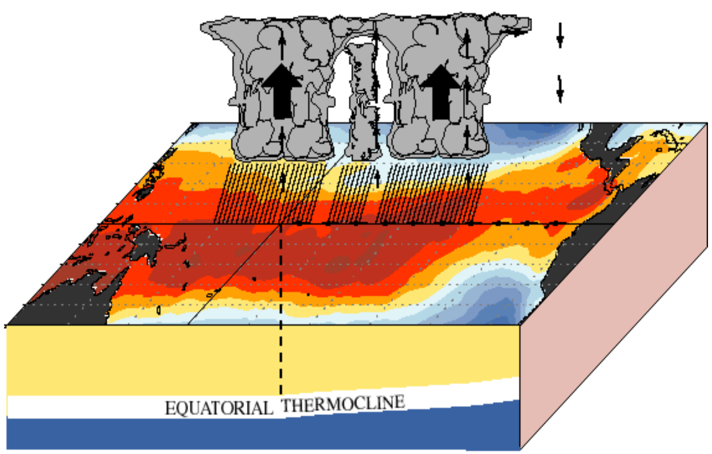
- The slow changes in the surface temperatures of the oceans are thought to impart a degree of predictability.

THE EL NIÑO/SOUTHERN OSCILLATION (ENSO) CYCLE

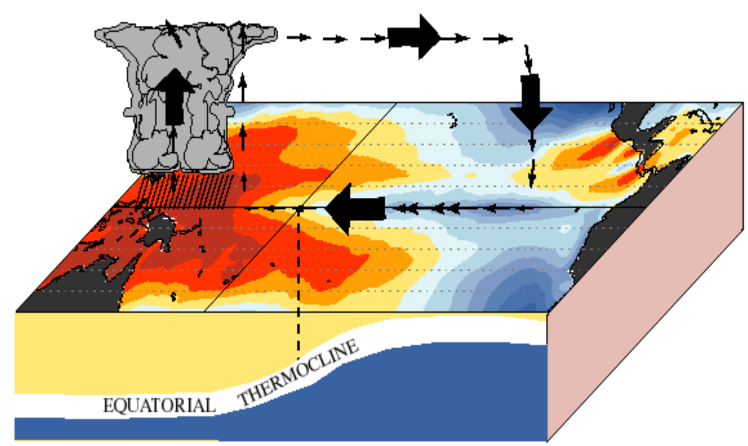
December - February Normal Conditions



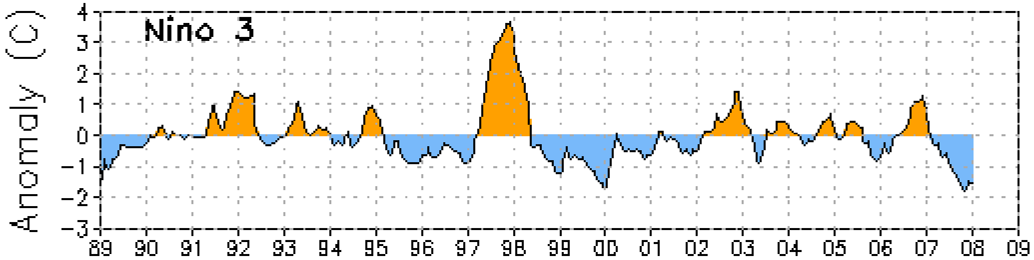
December - February El Niño Conditions



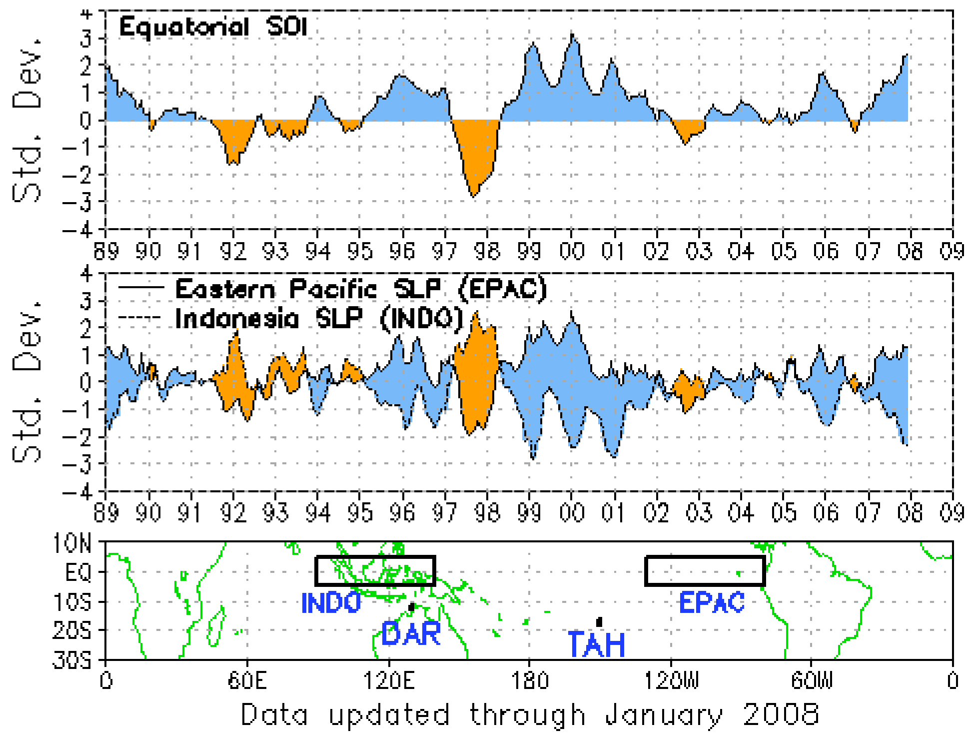
December - February La Niña Conditions



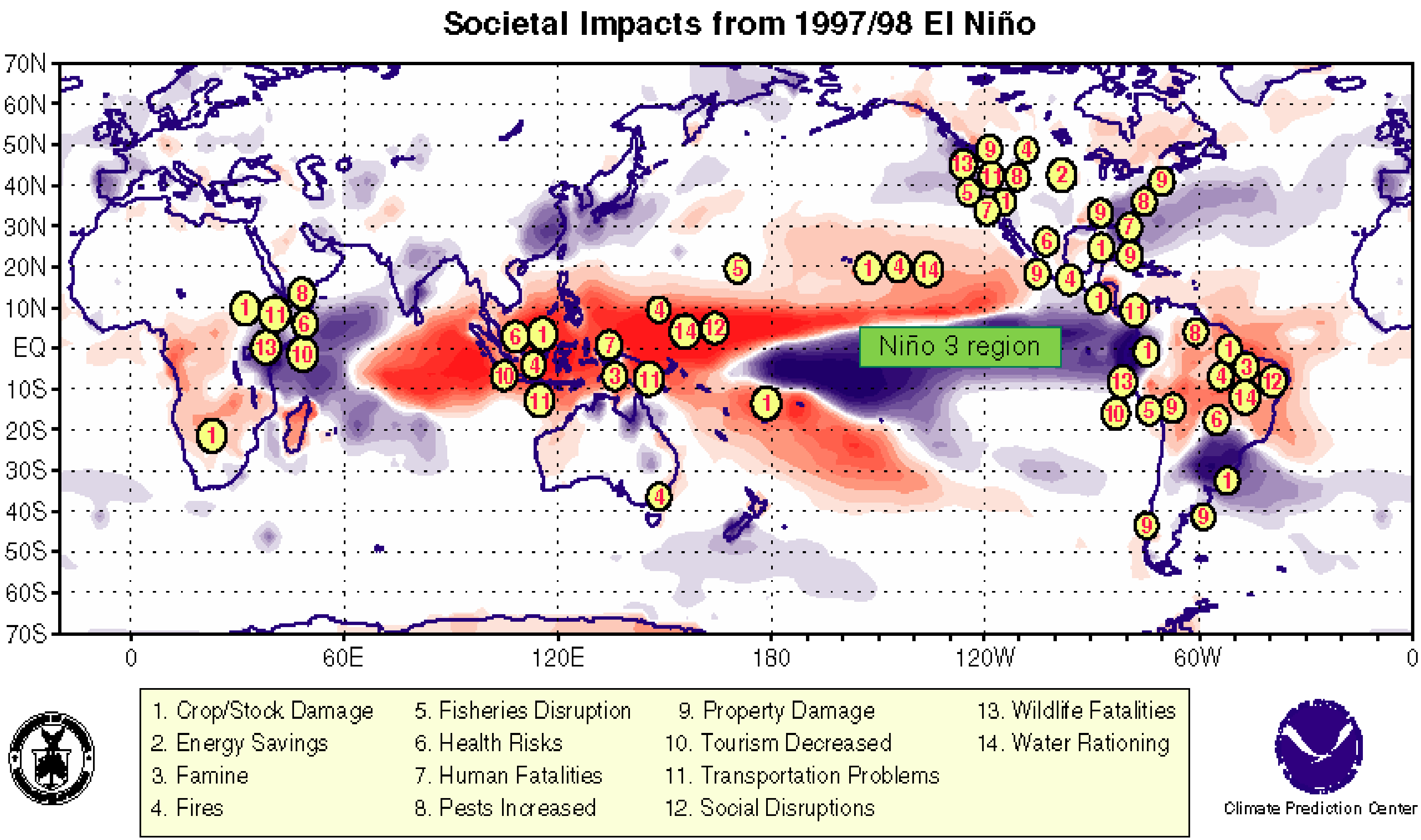
Sea Surface Temperature (SST) anomalies over the Equatorial Pacific:



Equatorial Southern Oscillation Index (SOI):



Weather-related natural disasters

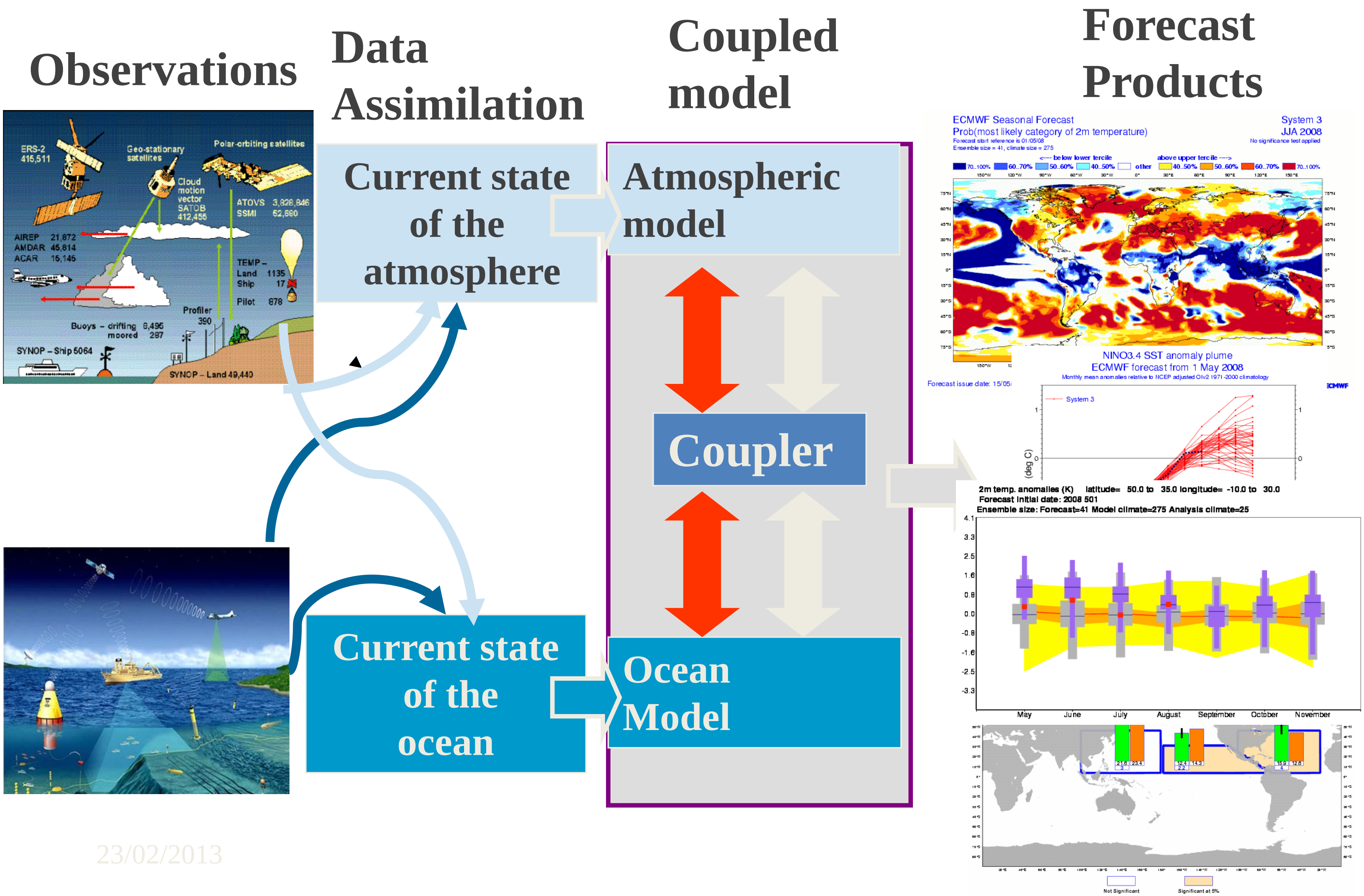


Seasonal Forecasting at ECMWF

In 1995 ECMWF started an experimental programme in seasonal forecasting. Successful predictions of the exceptional El Nino event of 1997 encouraged the Council to support the seasonal forecast activity.

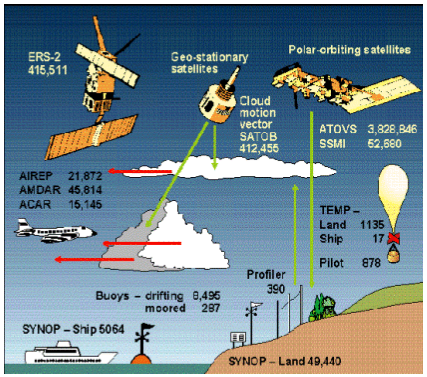
A range of seasonal products are issued routinely on http://www.ecmwf.int/products/forecasts/seasonal

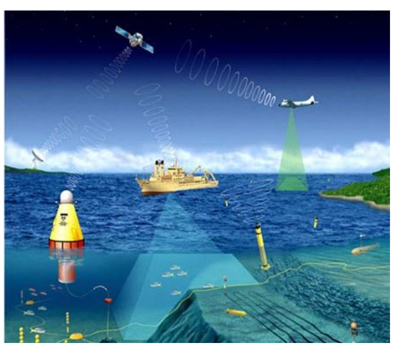
ECMWF Seasonal Forecasting System



ECMWF Seasonal Forecasting System

Observations





Data Assimilation

Current state of the atmosphere

Current state of the ocean

System 4

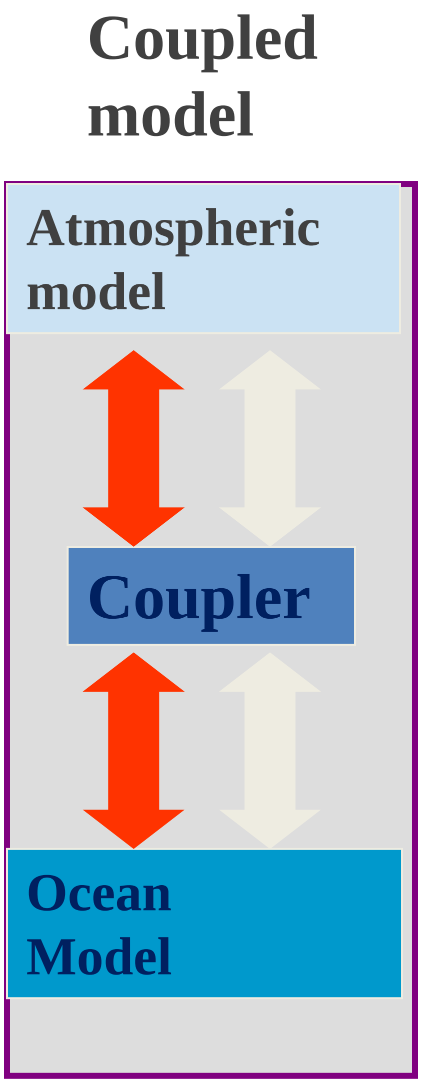
4-D variational d.a.

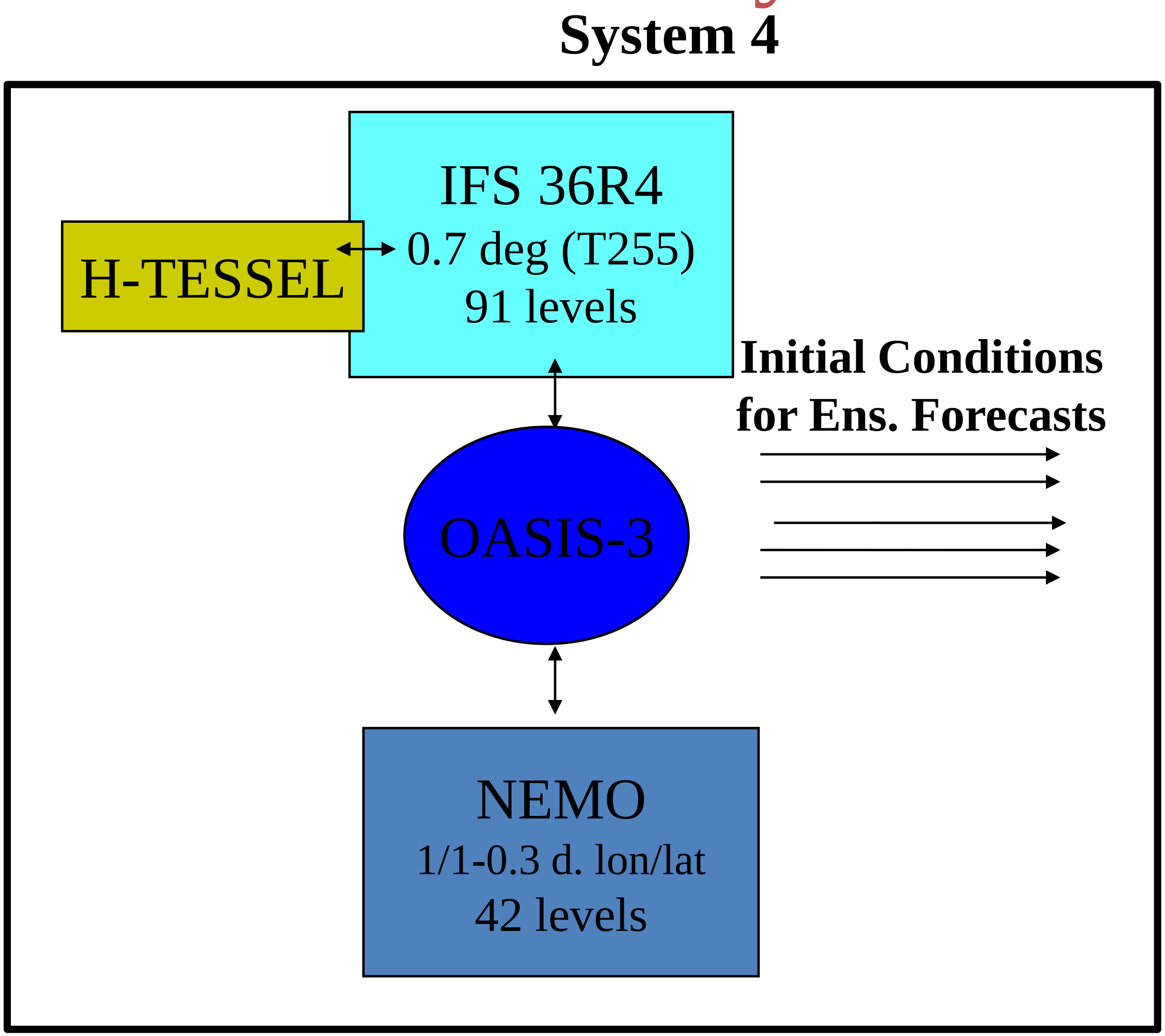
3-D v.d.a. (NEMOVAR)

Gen. of Perturb.

Initial Con.

The ECMWF Seasonal fc. system





ECMWF System 4: main features

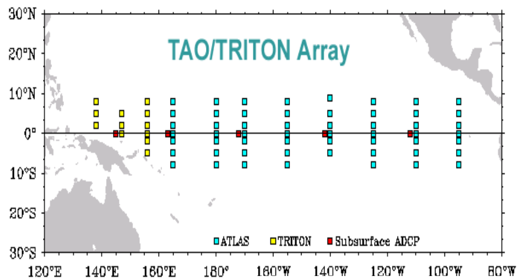
- **Operational forecasts**
  - **51-member ensemble from 1st day of the month**
  - **released on the 8th**
  - **7-month integration**

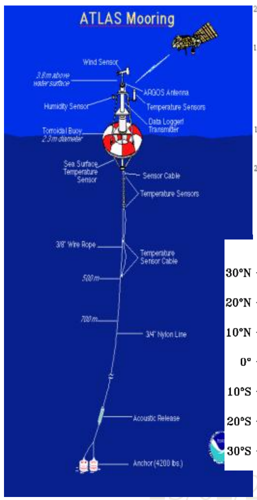
- **Re-forecast set**
  - **30 years, start dates from 1 Jan 1981 to 1 Dec 2010**
  - **15-member ensembles, 7-month integrations**
  - **13-month extension from 1st Feb/May/Aug/Nov**

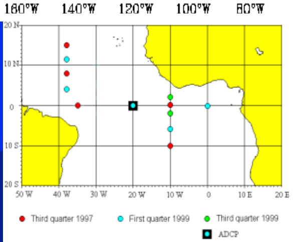
- **Experimental ENSO outlook**
  - **13-month extension from 1st Feb/May/Aug/Nov**
  - **15-member ensemble**

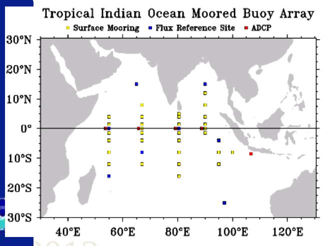
Real Time Ocean Observations

Moorings

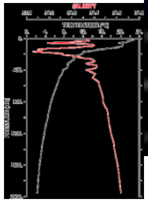


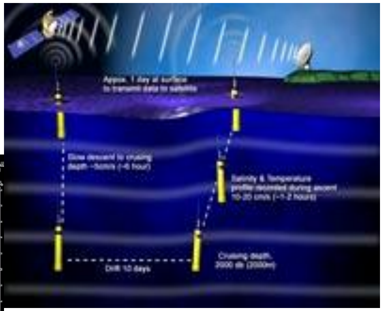


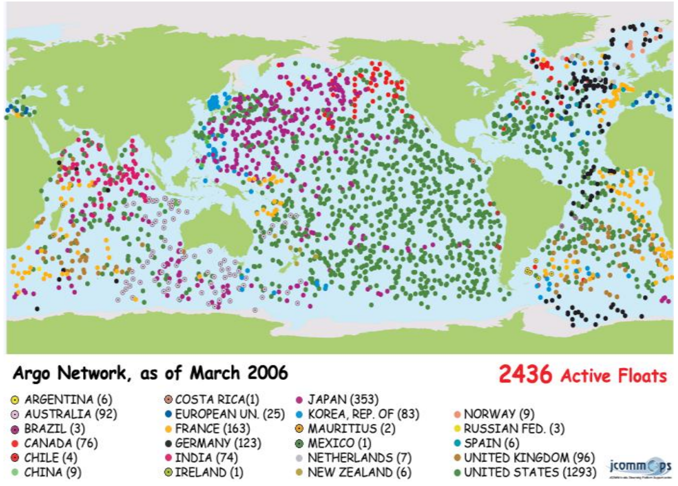




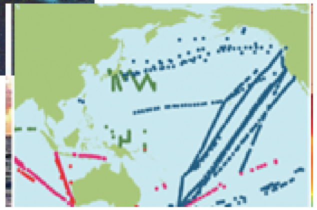
ARGO floats



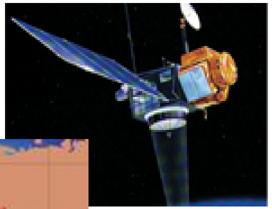


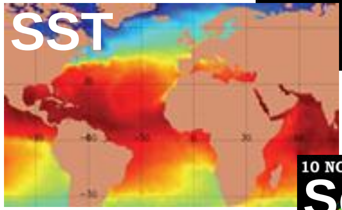


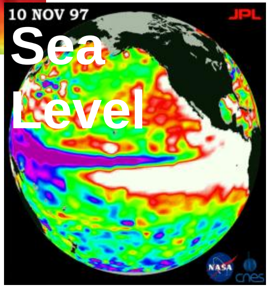
XBT (eXpendable BathiThermograh)



Satellite

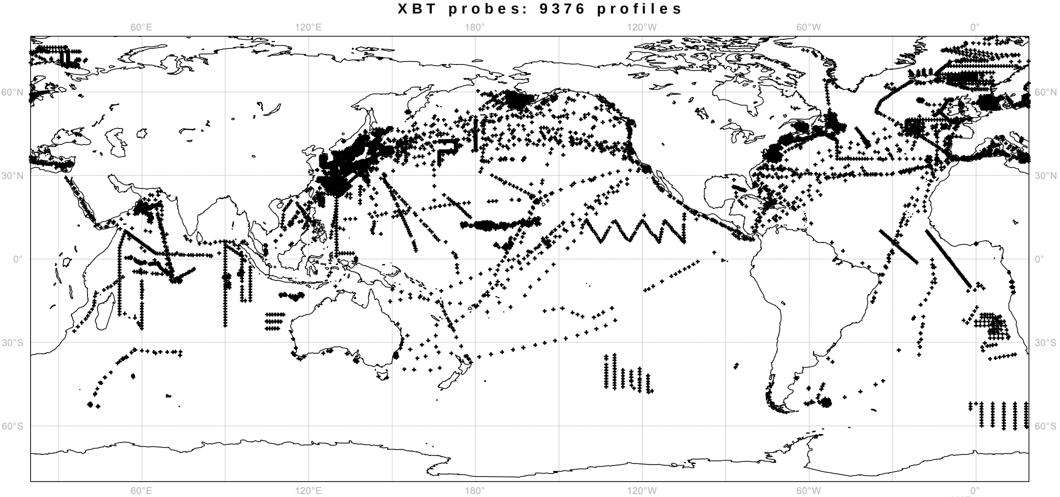






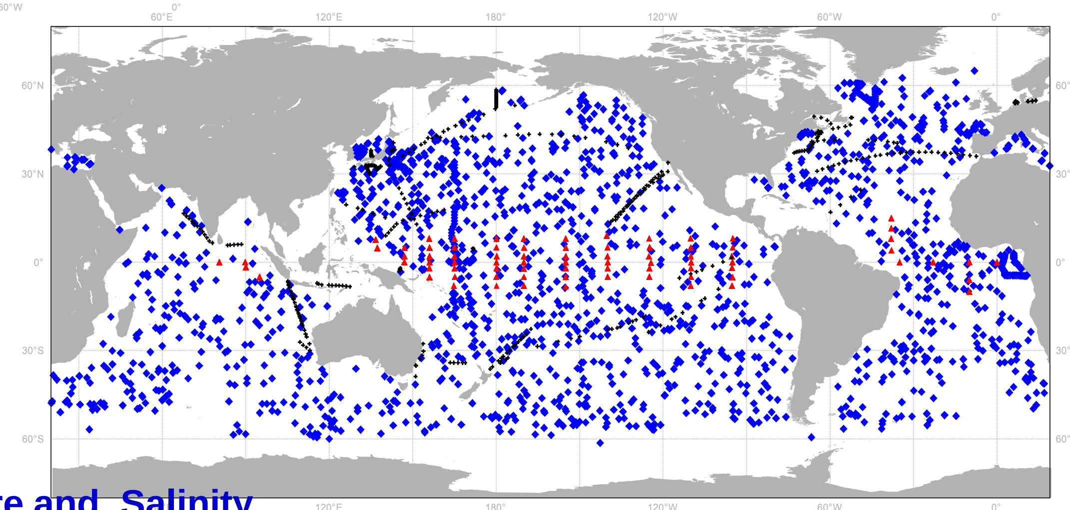
Ocean Observing System

Data coverage for June 1982



Changing observing system is a challenge for consistent reanalysis

Data coverage for Nov 2005



Today's Observations will be used in years to come

▲Moorings: Subsurface Temperature

◊ ARGO floats: Subsurface Temperature and Salinity

+ XBT : Subsurface Temperature

Chaotic nature of the atmosphere:

- To deal with the chaotic processes in the atmosphere we use an ensemble of simulations: on the 1st of the month 40 forecasts are run for 6 months. They have initial conditions from 5-member ensemble of ocean analyses (wind perturbations throughout analysis and SST perturbations at start of forecasts)

- Seasonal forecasting does not give exact predictions, but it may allow us to describe the probability that a certain weather event can happen.

Product generation:

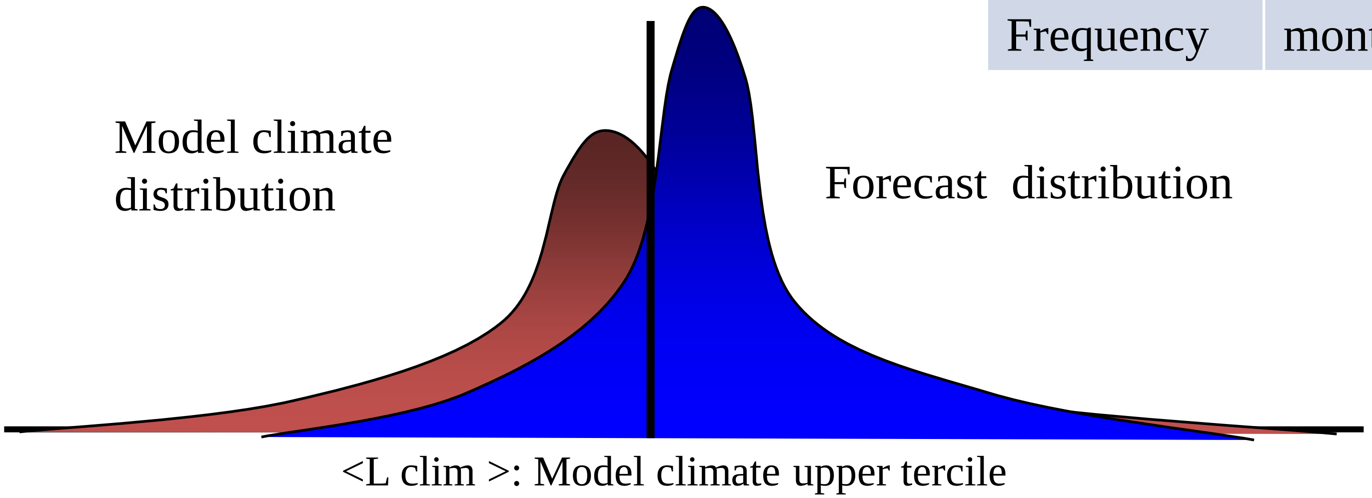
- Model drift, estimated by an ensemble of simulations started in previous years, is removed. This is based on the assumption that the atmospheric and oceanic anomalies have a linear behaviour.

Extended range predictions

• Products from Extended range predictions are generally defined with reference to the model climate estimated by the re-forecast data.

• Post-processing/calibration of model data is indispensable for the extended range forecasts.

Re-forecast	Seasonal
Period	30 years
Ens. Size	15
Frequency	monthly



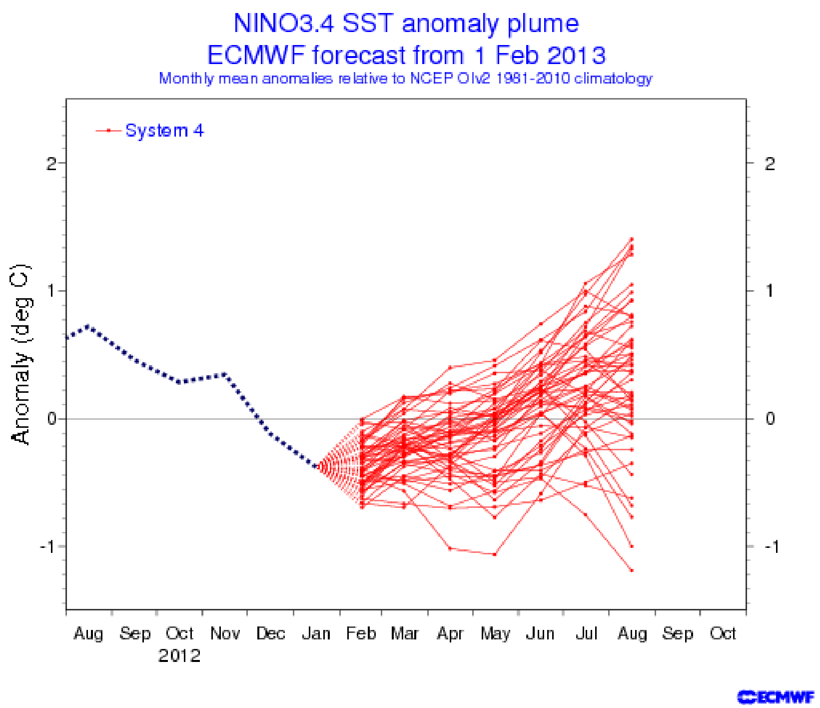
Products :

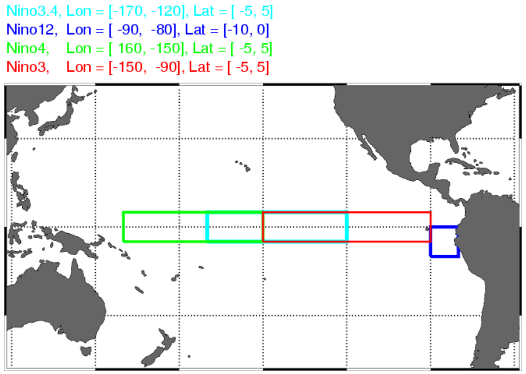
- Ocean Analysis

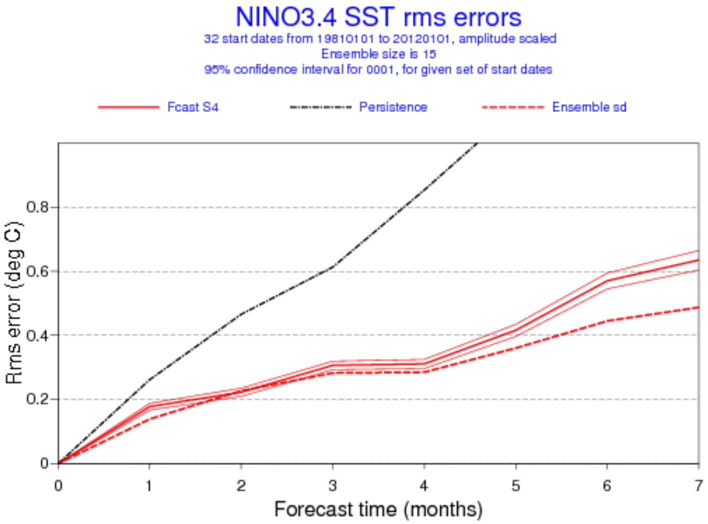
- Seasonal outlook: (up to 6 months ahead)
  - Forecasts for Nino3, Nino3.4 and Nino4
  - Spatial plots (ens.mean anomaly, terciles ..)
  - Climagrams (similar to Epsgrams)
  - Tropical storms

- Annual outlook: (up to 10 months ahead)
  - Forecasts for Nino3, Nino3.4 and Nino4
  - Spatial plots (ens.mean anomaly, terciles ..)
  - Tropical storms

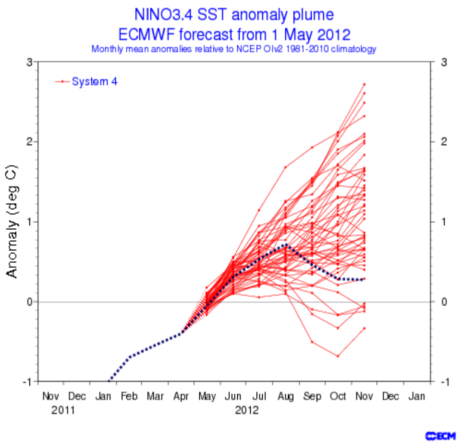
NINO3.4 plumes

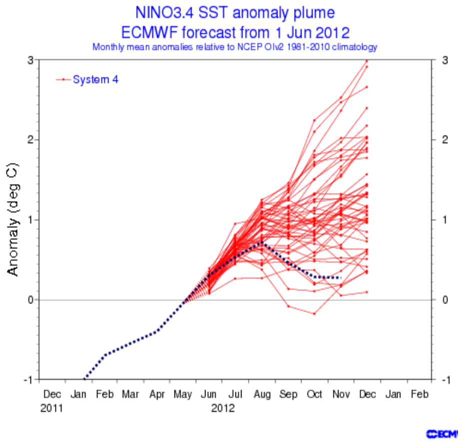


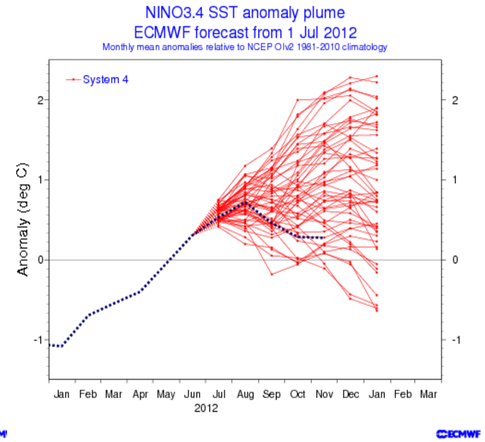


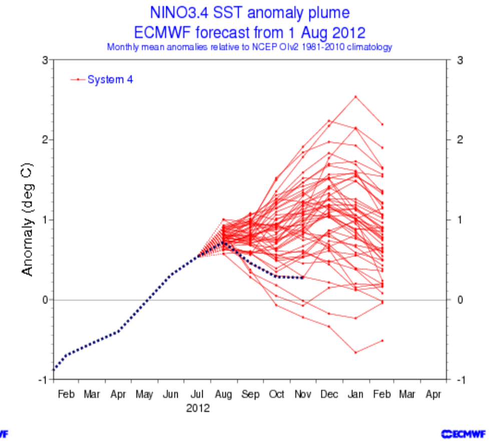


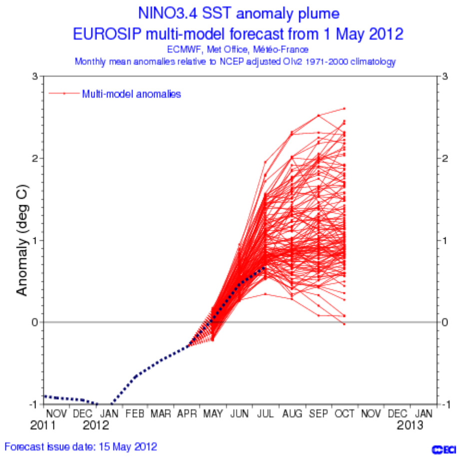
NINO 3.4 past predictions

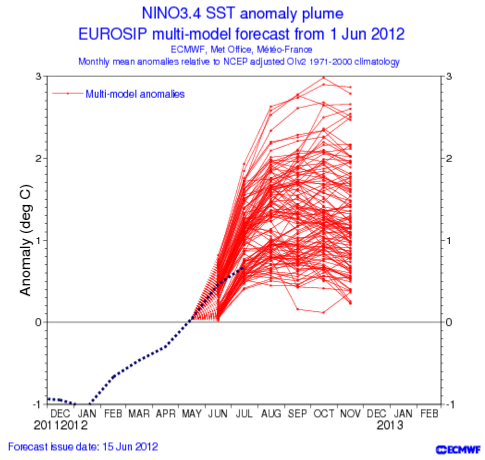


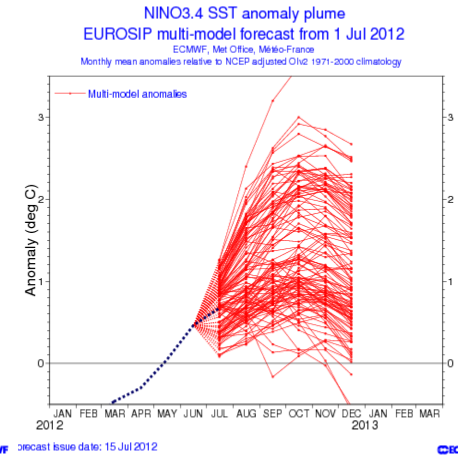


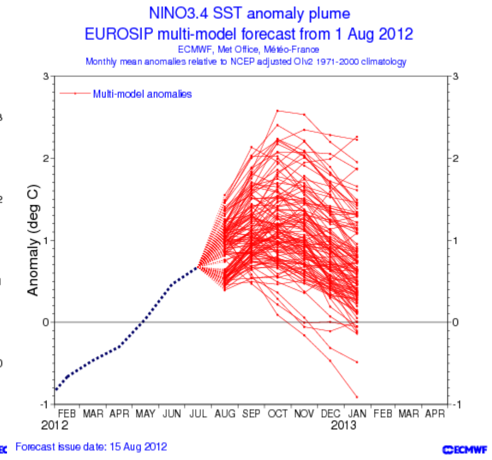




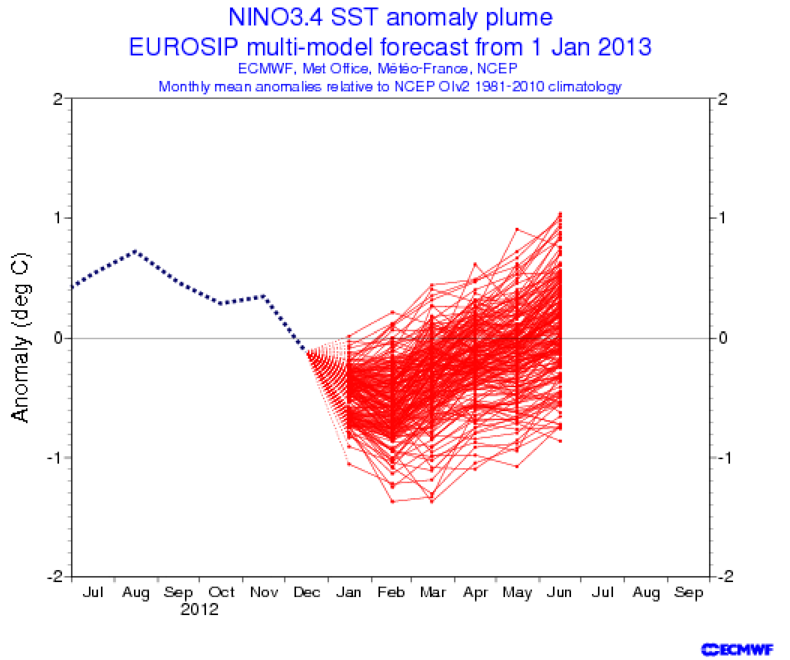


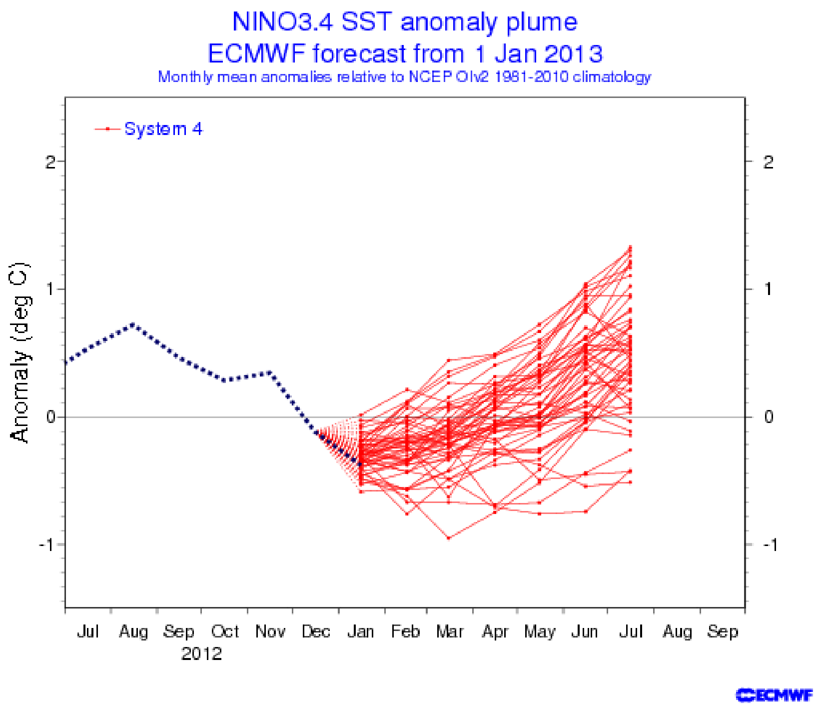


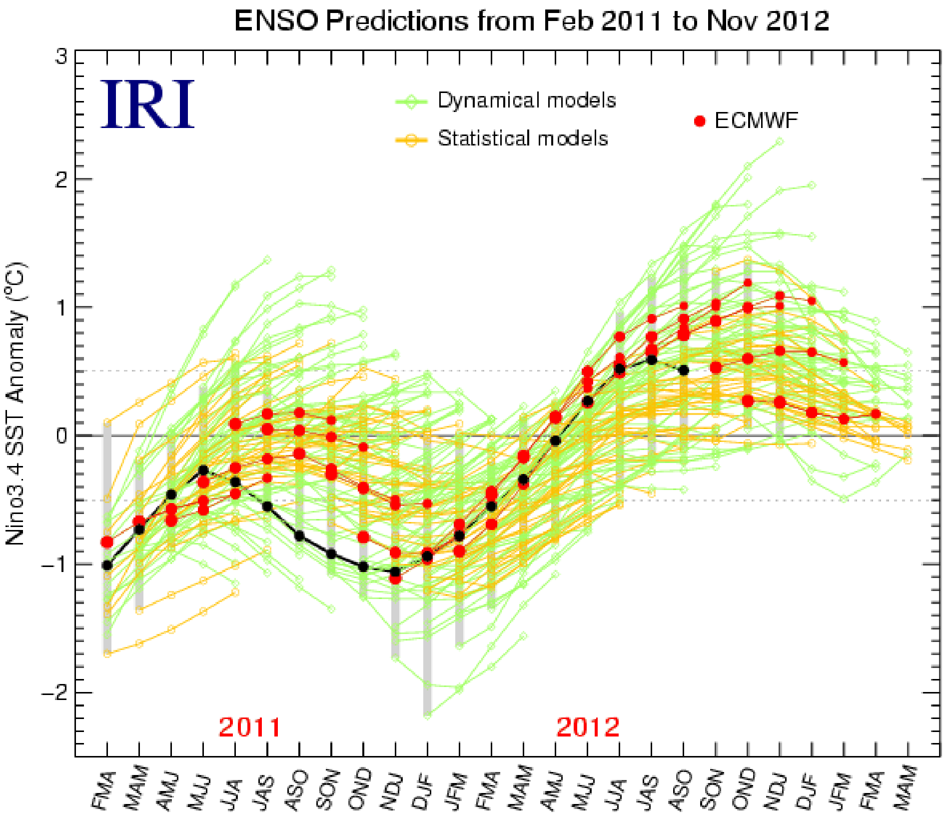




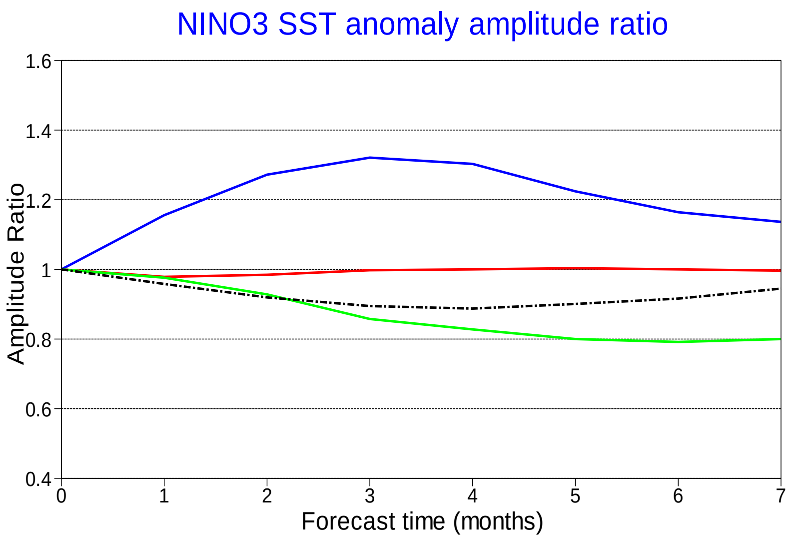
Nino 3.4 outlook

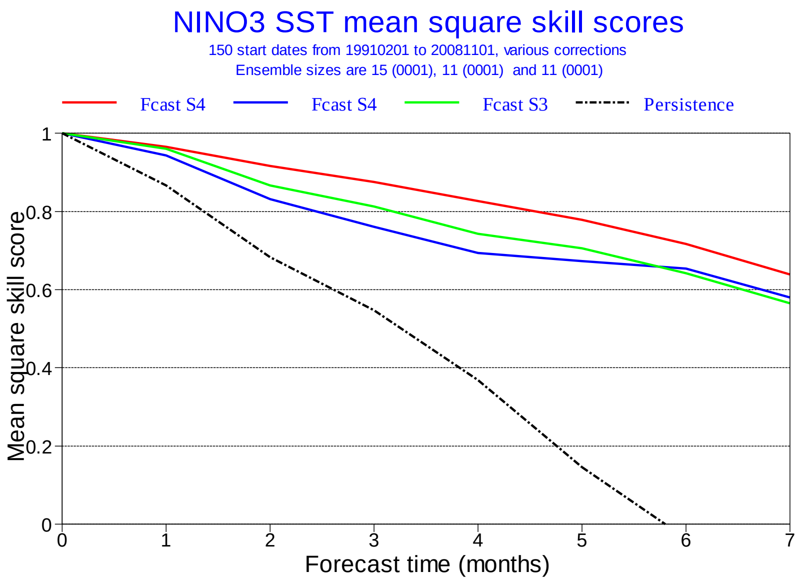






Calibration of ENSO SST indices



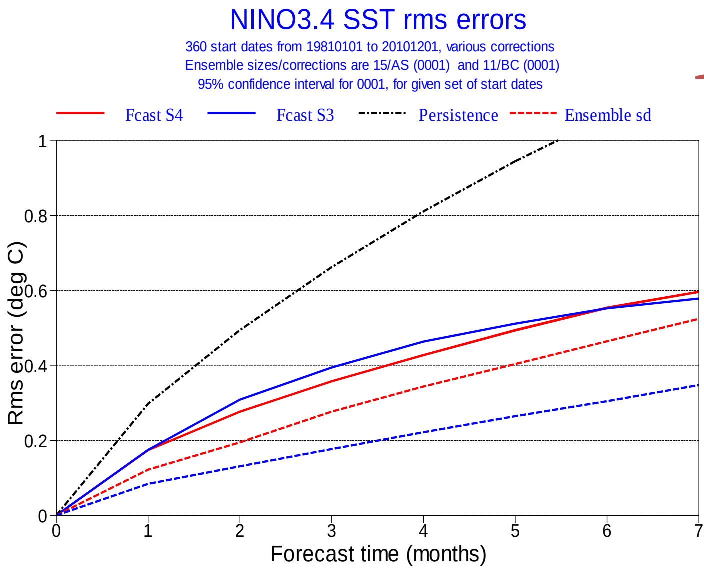


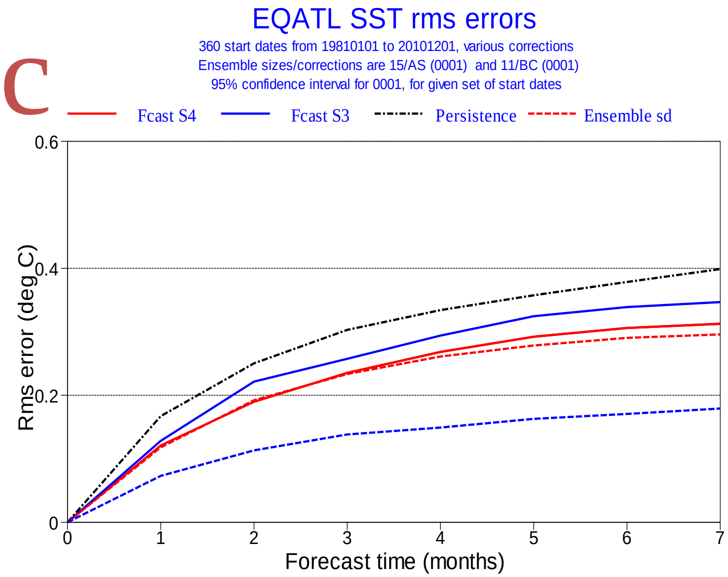
S4 non calib.

S4 calibrated

S3

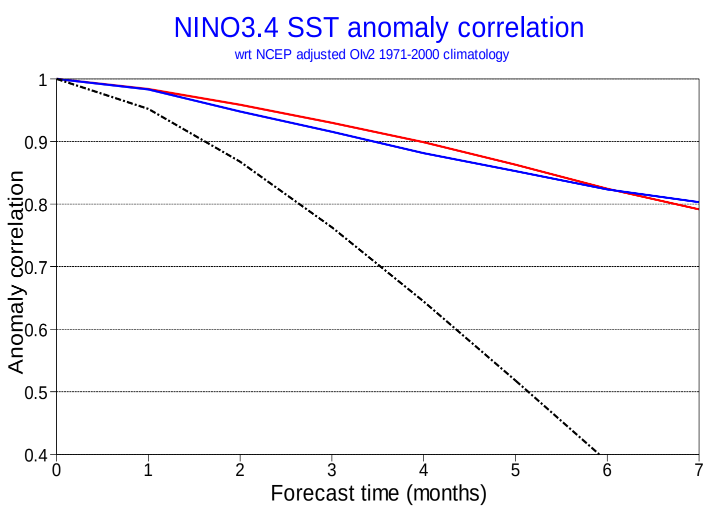
SST scores: Nino 3.4 and Eq. Atlantic

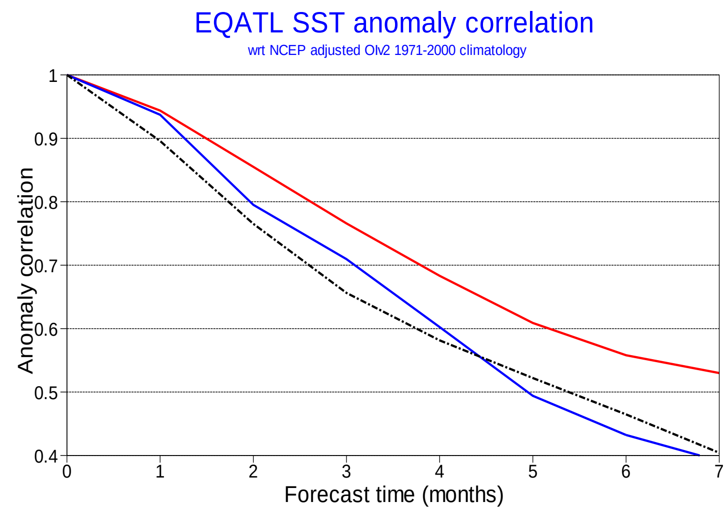




Solid:
S4 error
S3 error
Dashed:
S4 spread
S3 spread

S4 ACC
S3 ACC
Pers. ACC

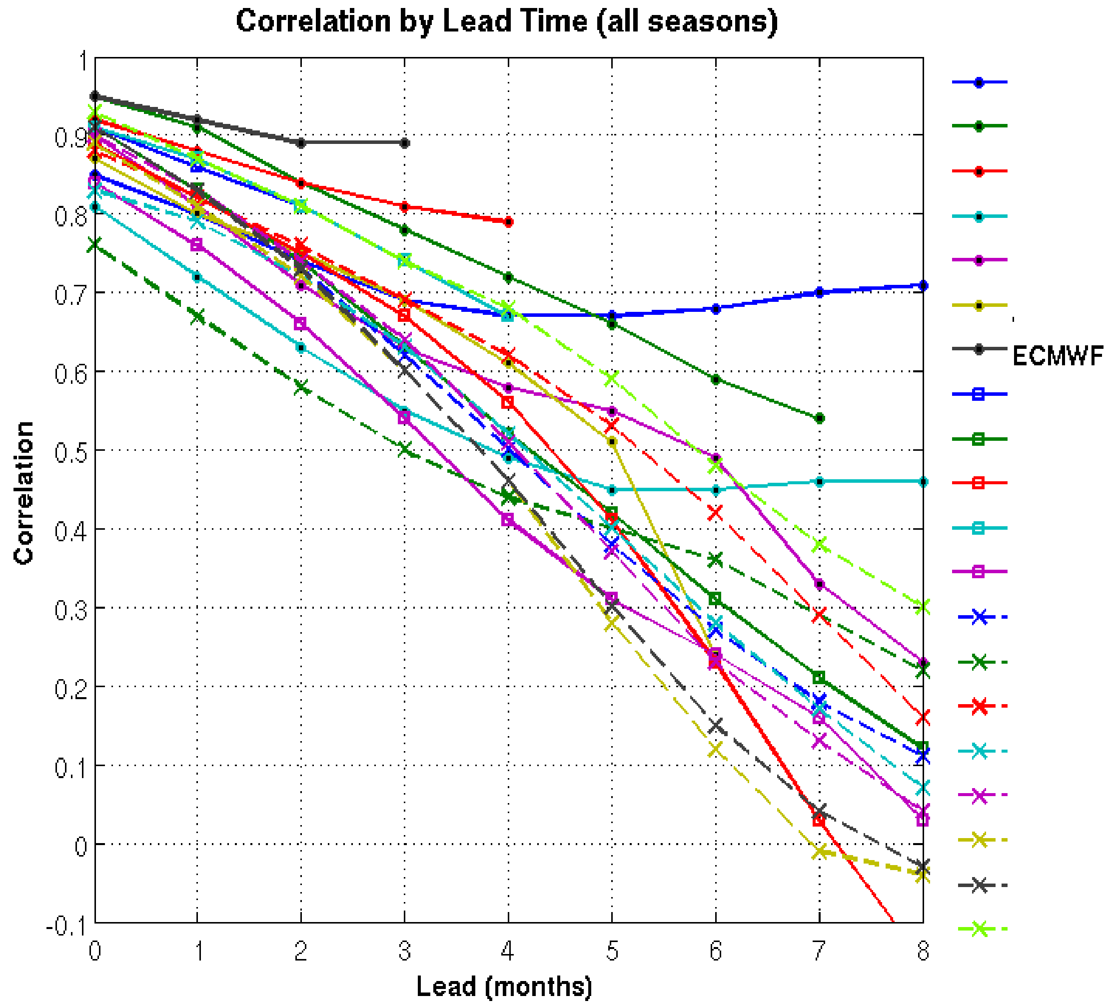




ENSO skill: comparison with other seasonal fc. systems

NINO3.4 Anomaly Correlation

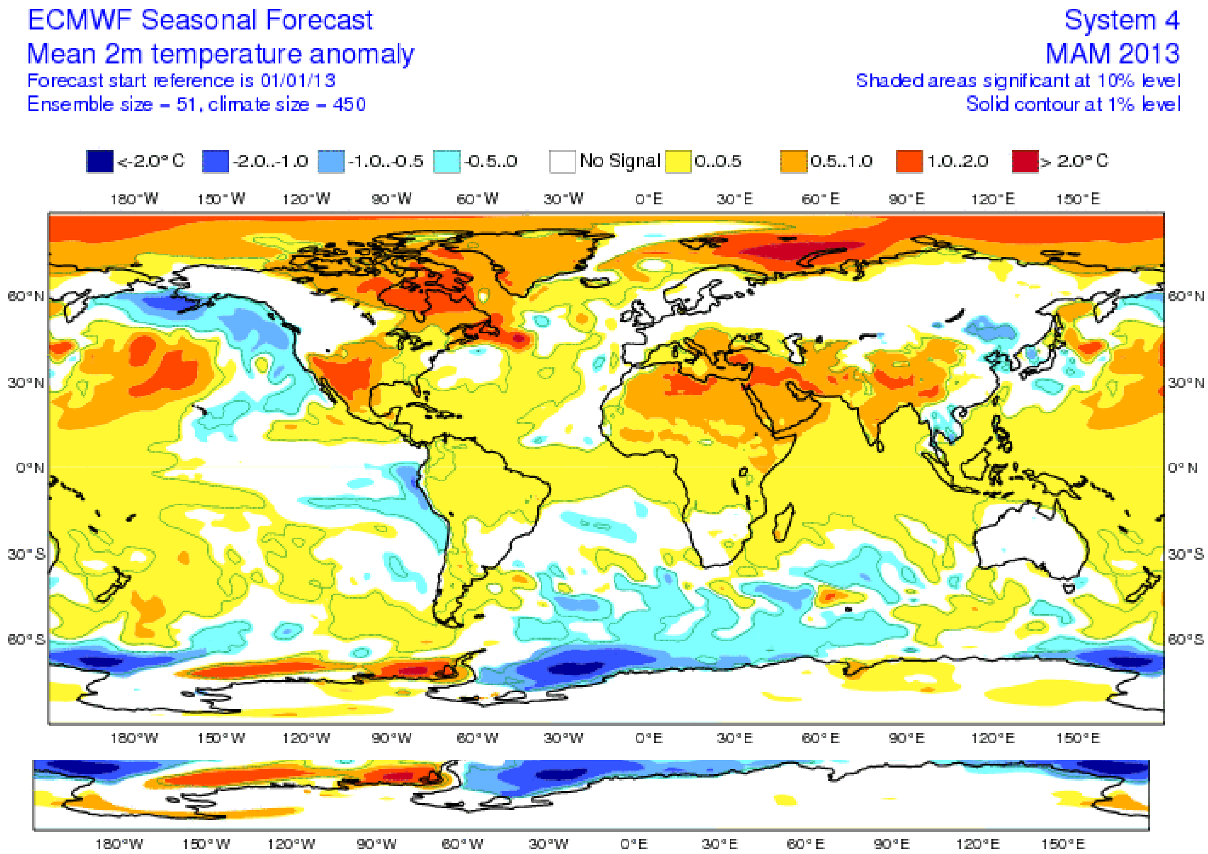
3-month running means



From: Barnston et al. 2011: Skill of Real-time Seasonal ENSO Model Predictions during 2002-2011—Is Our Capability Increasing? BAMS, accepted

Seasonal forecast charts :

Spatial maps representing the seasonal forecast in terms of model probabilities stratified by terciles.



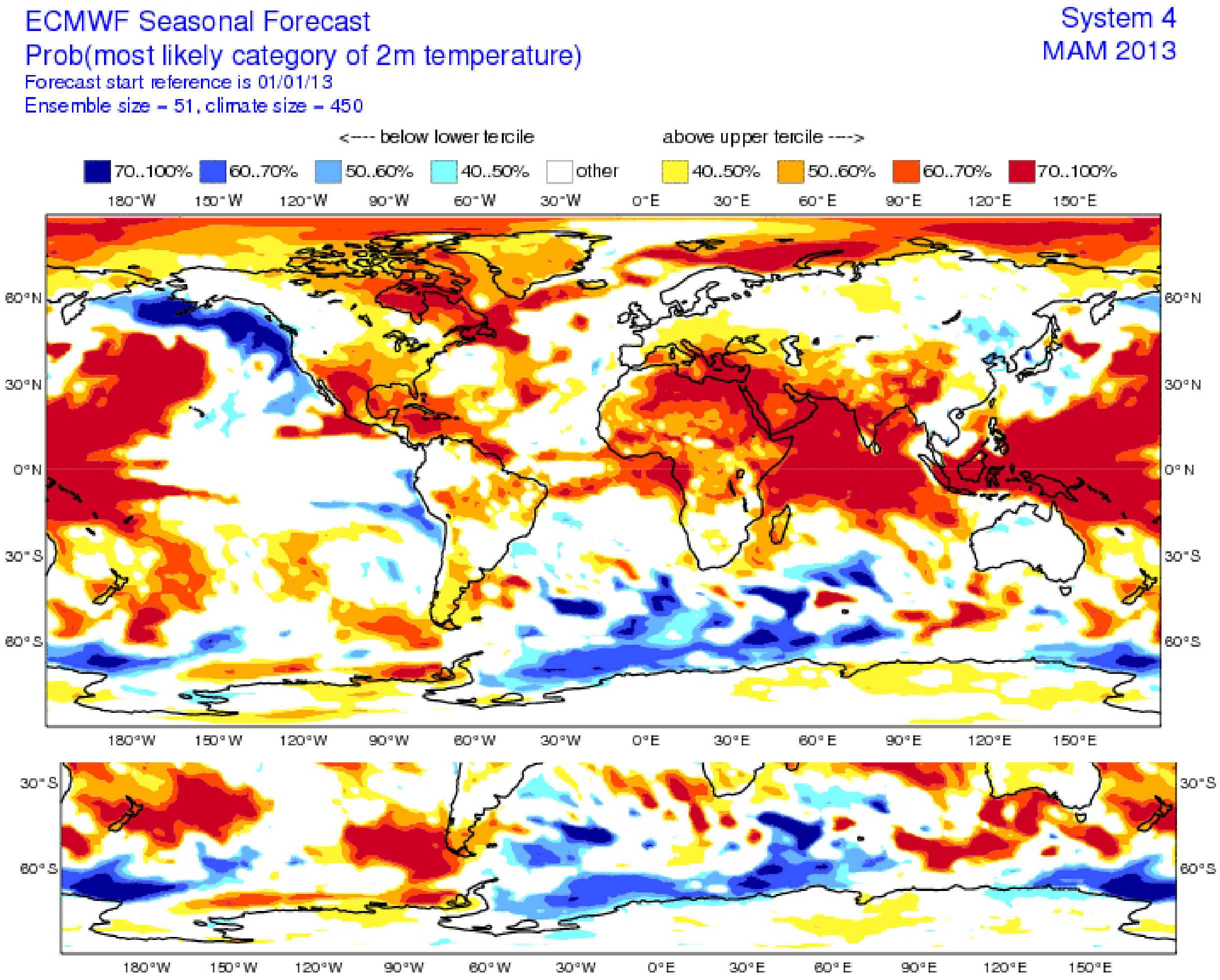
Available parameters are:

- 2m Temperature
- Mean sea level pressure
- Precipitation
- Sea surface temperature
- 850 hPa temperature
- 500 hPa geopotential

Forecast is made available on the 8h of each month.

Seasonal forecast charts :

Spatial maps representing the seasonal forecast in terms of model probabilities stratified by terciles.



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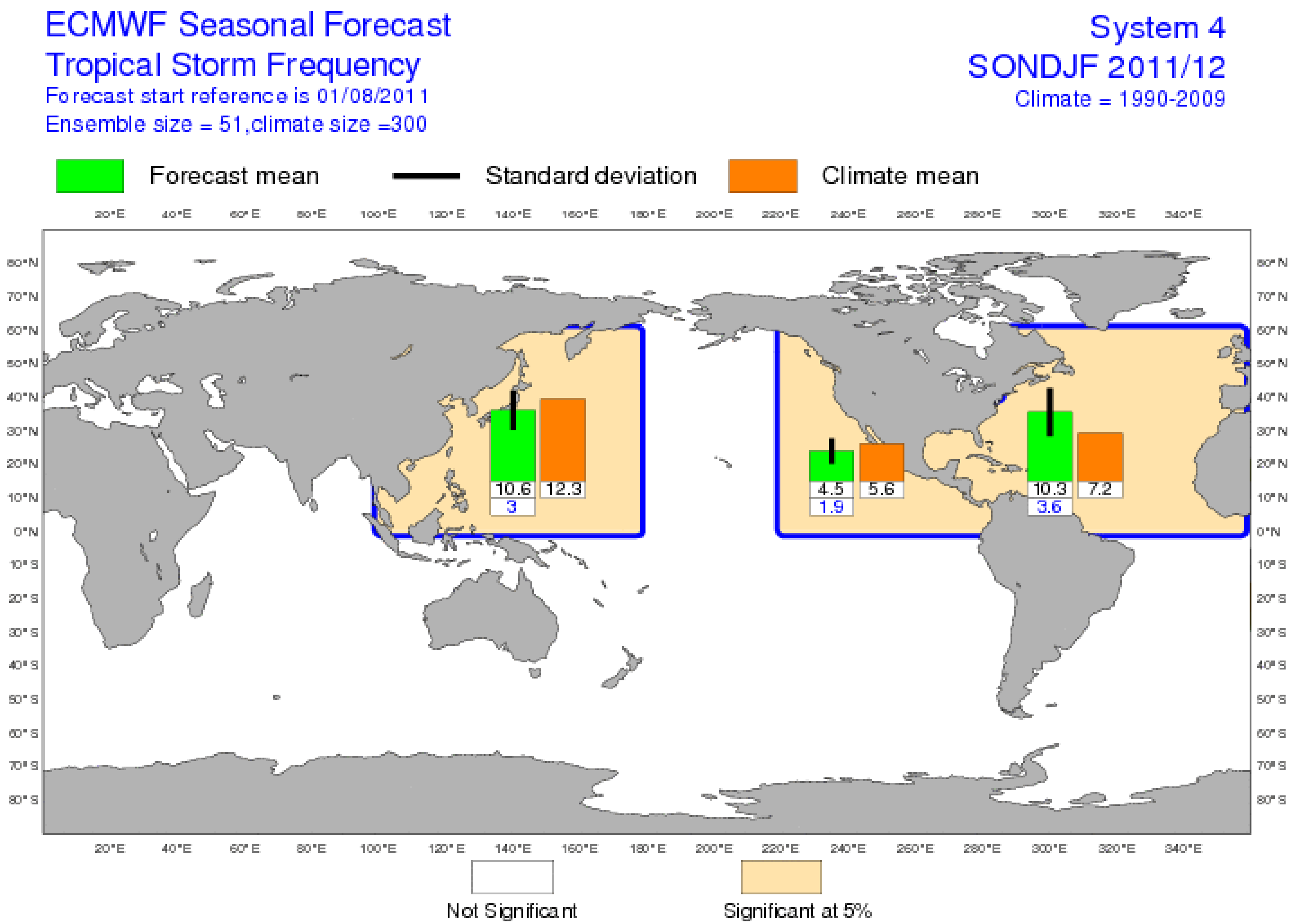
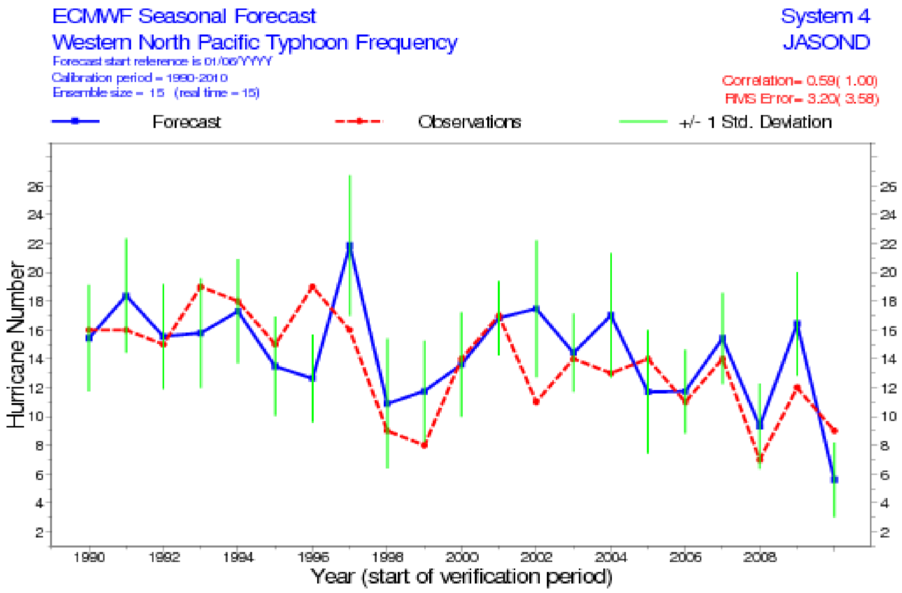
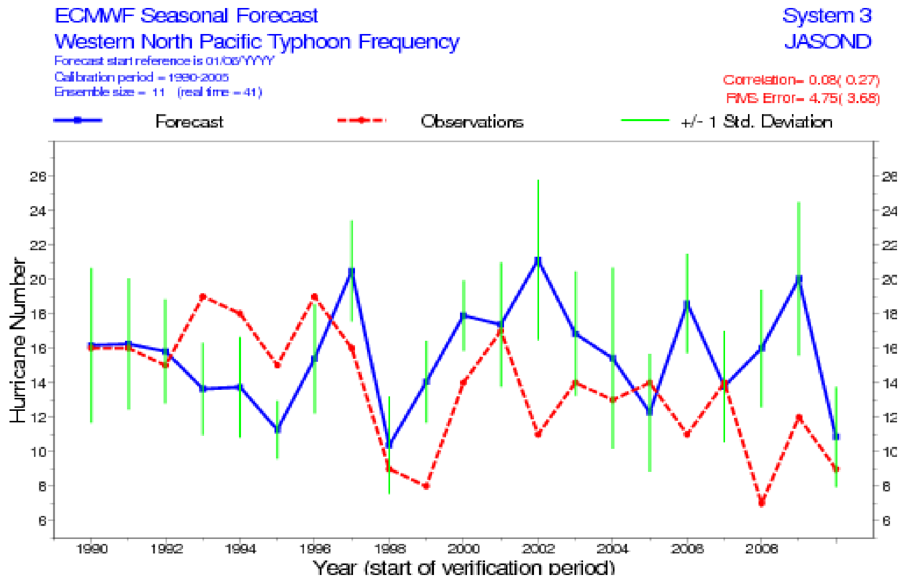

ECMWF Seasonal Forecast
Tropical Storm Frequency
Forecast start reference is 01/08/2011
Ensemble size = 51,climate size =300
System 4
SONDJF 2011/12
Climate = 1990-2009
Forecast mean
Standard deviation
Climate mean
10.6
12.3
3
4.5
5.6
1.9
10.3
7.2
3.6
Not Significant
Significant at 5%

Prediction of tropical cyclone frequency: NW Pacific



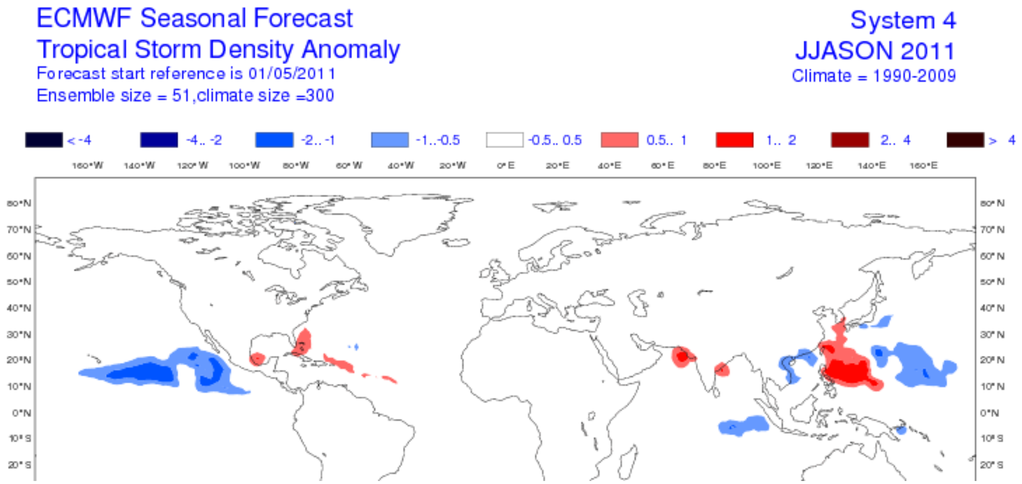


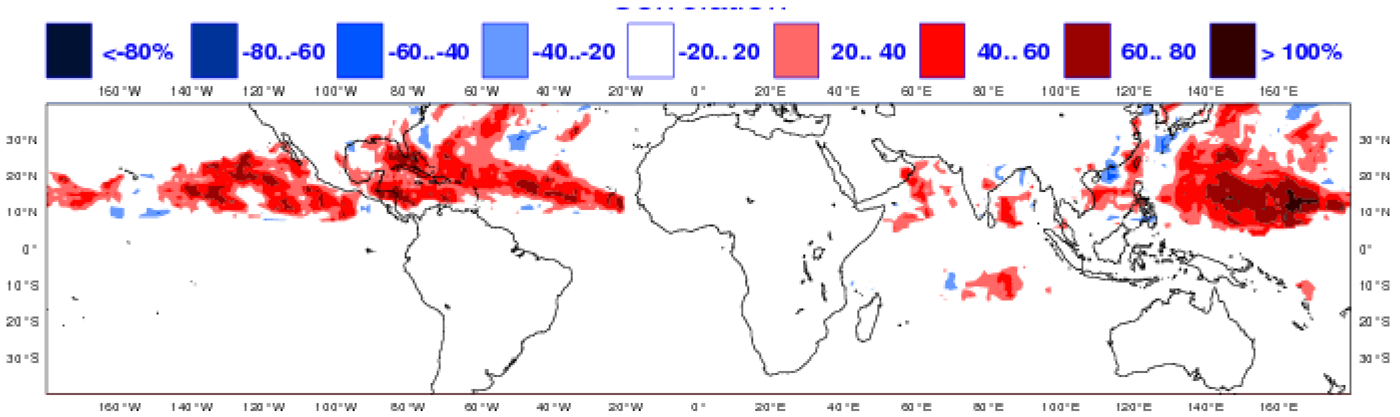
System 4
vs. ERA-Int.

July-Dec.
1990-2010

System 3
vs. ERA-Int.

Cyclone track density new product from S4 and its verification





Track density for the July-Dec. period from fc. started on 1 May 1990-2010

Bias in S4 re-forecasts: SST (DJF)

Start: 1 Nov.

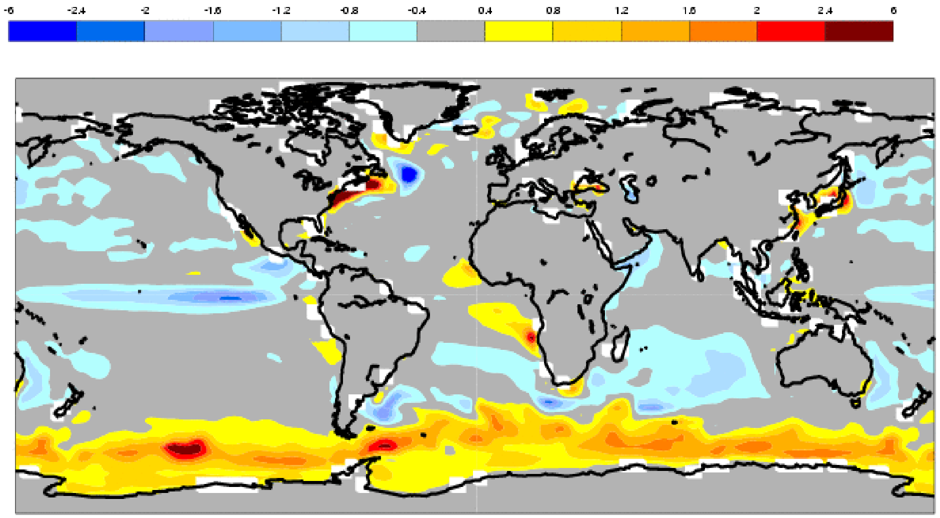
1981/2010

Verify: Dec-Feb

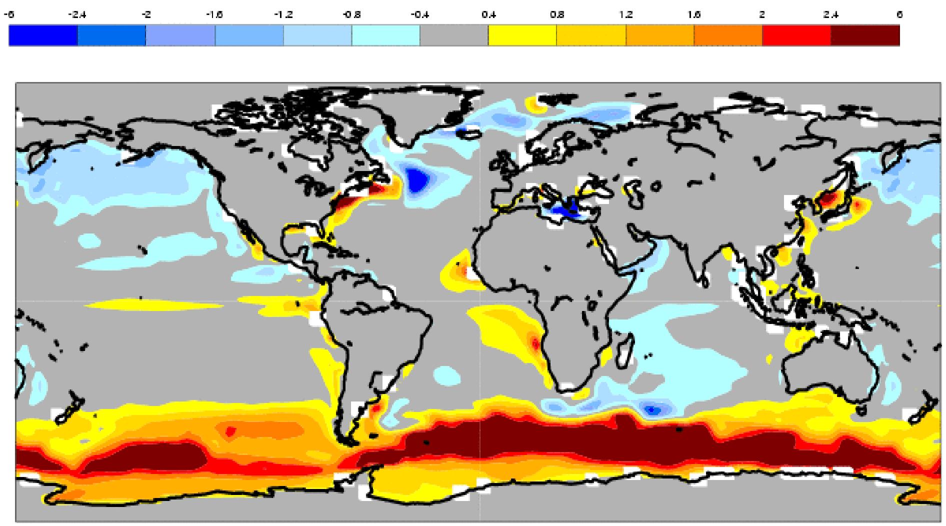
Sea Surface temperature

Hindcast period 1981-2010 with start in November average over months 2 to 4

System 4



System 3



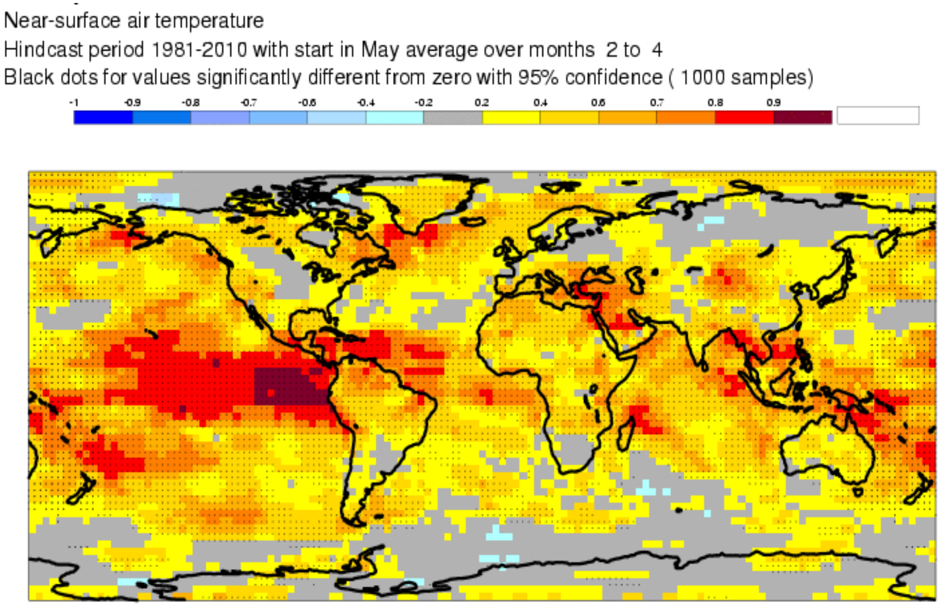
Ens-mean ACC in S4 re-forecasts: 2m T (JJA)

Start: 1 May

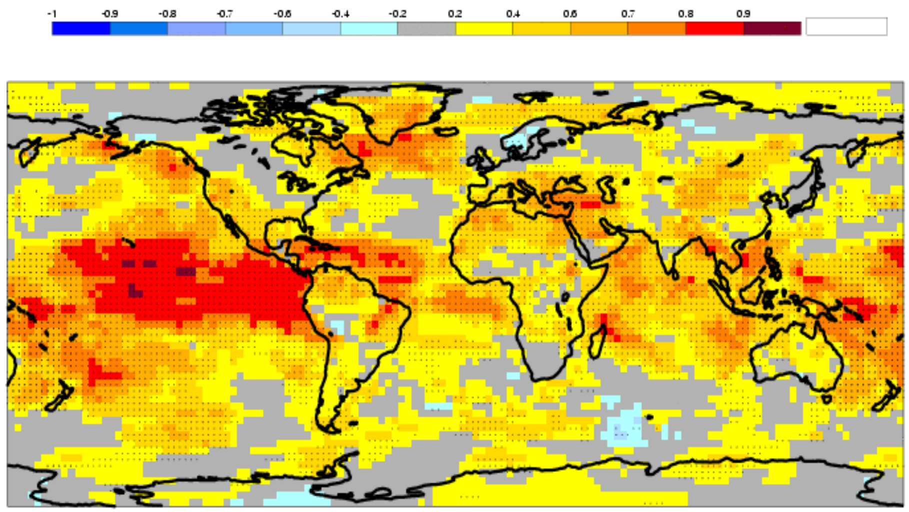
1981/2010

Verify: Jun-Aug

System 4



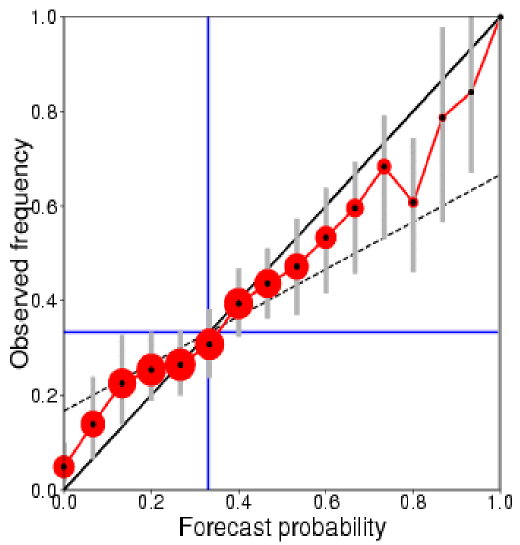
System 3



Reliability: 2m T > upper tercile over Europe, JJA

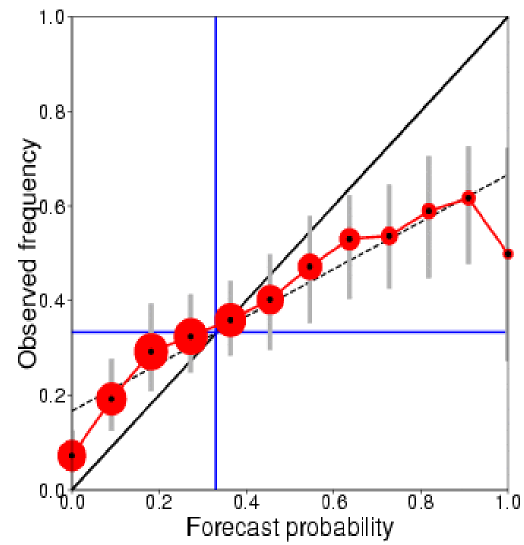
Sys 4

Reliability diagram for ECMWF with 15 ensemble members
Near-surface air temperature anomalies above the upper tercile
Accumulated over Europe (land and sea points)
Hindcast period 1981-2010 with start in May average over months 2 to 4
Skill scores and 95% conf. intervals (1000 samples)
Brier skill score: 0.092 (0.007, 0.162)
Reliability skill score: 0.986 (0.950, 0.994)
Resolution skill score: 0.106 (0.056, 0.173)



Sys3

Reliability diagram for ECMWF with 11 ensemble members
Near-surface air temperature anomalies above the upper tercile
Accumulated over Europe (land and sea points)
Hindcast period 1981-2010 with start in May average over months 2 to 4
Skill scores and 95% conf. intervals (1000 samples)
Brier skill score: 0.031 (-0.045, 0.094)
Reliability skill score: 0.943 (0.891, 0.965)
Resolution skill score: 0.089 (0.056, 0.133)

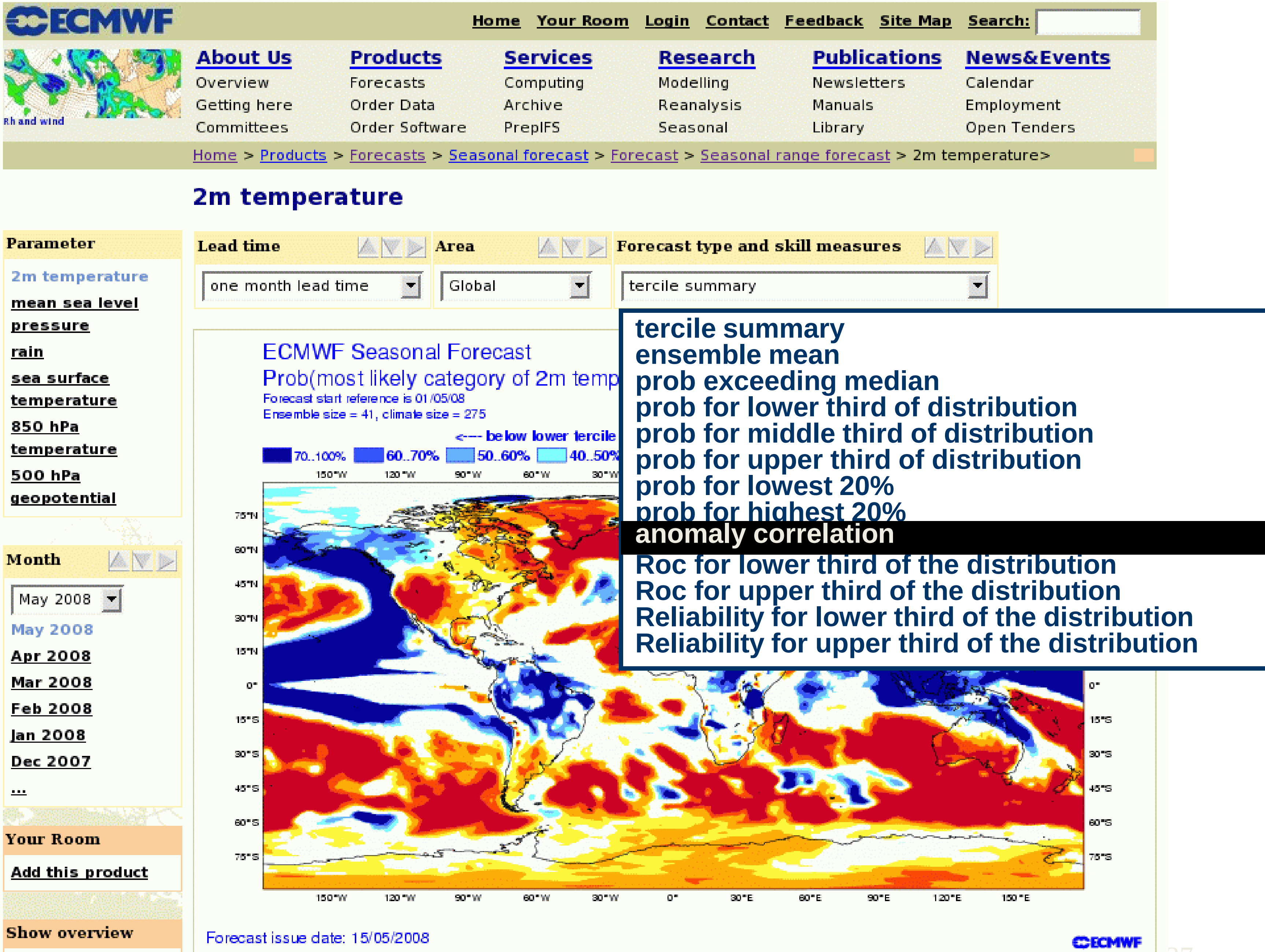


Validation :

- Documentation of skill levels is provided to the users:

- The measure of skill conforms to a common standard defined by the WMO

- The verification sampling for seasonal forecast is limited, importance of significance levels in the verification statistics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2m temperature
Parameter
2m temperature
mean sea level pressure
rain
sea surface temperature
850 hPa temperature
500 hPa geopotential
Month
May 2008
May 2008
Apr 2008
Mar 2008
Feb 2008
Jan 2008
Dec 2007
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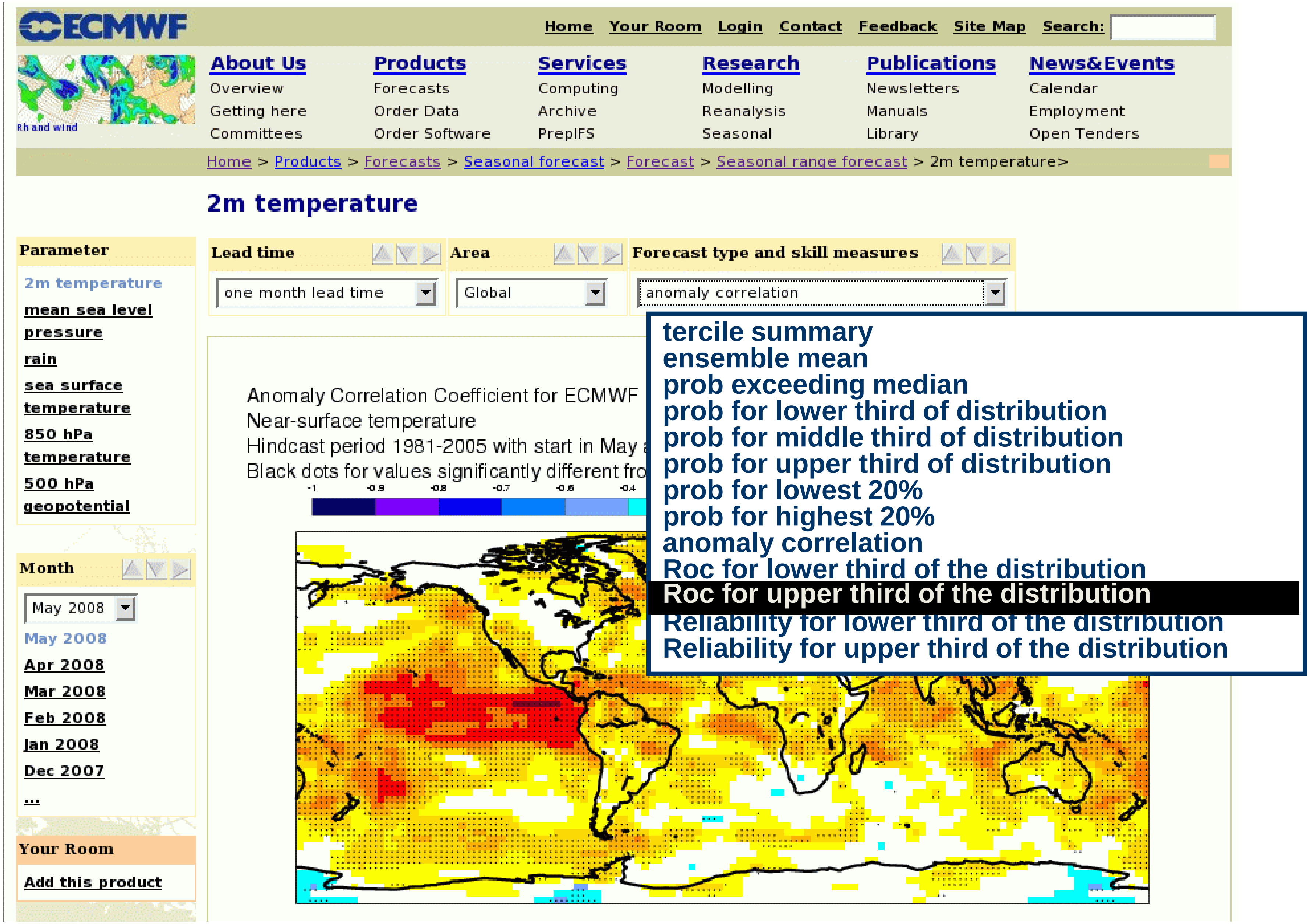
one month lead time
Area
Global
Forecast type and skill measures
tercile summary
ECMWF Seasonal Forecast
Prob(most likely category of 2m temp
Forecast start reference is 01/05/08
Ensemble size = 41, climate size = 275
<--- below lower tercile
70..100% 60..70% 50..60% 40..50%
150°W 120°W 90°W 60°W 30°W 0° 30°E 60°E 90°E 120°E 150°E
75°N 60°N 45°N 30°N 15°N 0° 15°S 30°S 45°S 60°S 75°S
Forecast issue date: 15/05/2008
ECMWF
tercile summary
ensemble mean
prob exceeding median
prob for lower third of distribution
prob for middle third of distribution
prob for upper third of distribution
prob for lowest 20%
prob for highest 20%
anomaly correlation
Roc for lower third of the distribution
Roc for upper third of the distribution
Reliability for lower third of the distribution
Reliability for upper third of the distribution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Forecast type and skill measures
anomaly correlation
Anomaly Correlation Coefficient for ECMWF
Near-surface temperature
Hindcast period 1981-2005 with start in May a
Black dots for values significantly different fro
-1 -0.9 -0.8 -0.7 -0.6 -0.4
tercile summary
ensemble mean
prob exceeding median
prob for lower third of distribution
prob for middle third of distribution
prob for upper third of distribution
prob for lowest 20%
prob for highest 20%
anomaly correlation
Roc for lower third of the distribution
Roc for upper third of the distribution
Reliability for lower third of the distribution
Reliability for upper third of the distribution

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2m temperature

Parameter

2m temperature
mean sea level pressure
rain
sea surface temperature
850 hPa temperature
500 hPa geopotential

Lead time

one month lead time

Area

Global

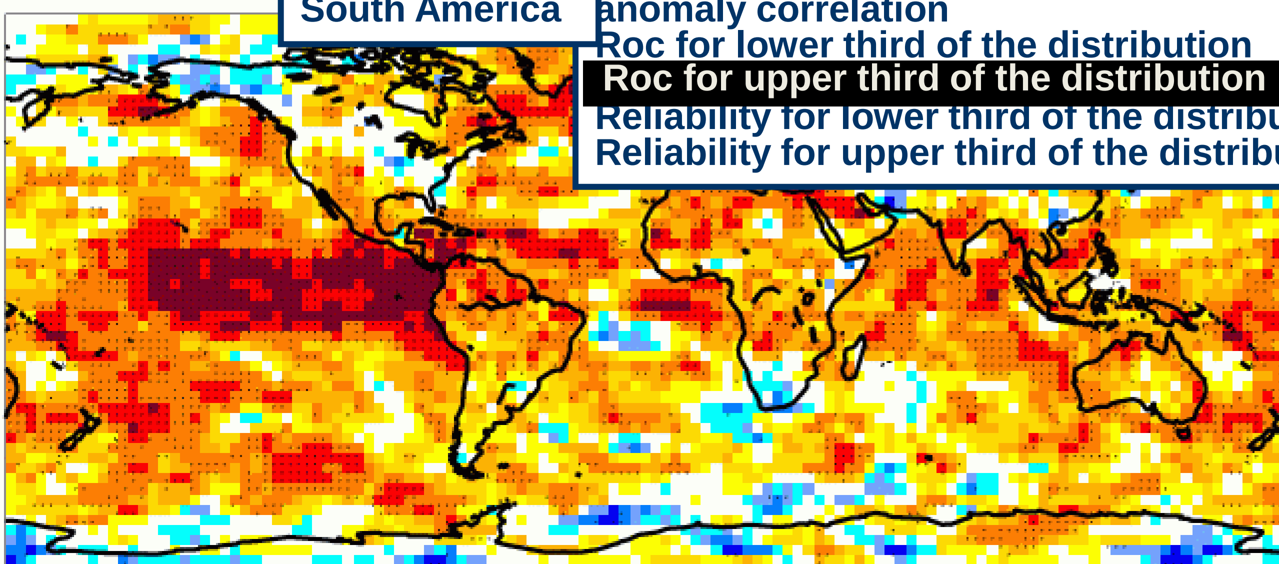
Global
Tropics
Europe
Africa
East Asia
Asia
Australasia
North America
South America

Forecast type and skill measures

ROC for upper third of the distribution

tercile summary
ensemble mean
prob exceeding median
prob for lower third of distribution
prob for middle third of distribution
prob for upper third of distribution
prob for lowest 20%
prob for highest 20%
anomaly correlation
Roc for lower third of the distribution
Roc for upper third of the distribution
Reliability for lower third of the distribution
Reliability for upper third of the distribution

ROC Skill Score for ECMW
Near-surface temperature
Hindcast period 1981-200
Threshold computed ranki
Black dots for values signi



Month

May 2008

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2m temperature

Parameter

- 2m temperature
- mean sea level pressure
- rain
- sea surface temperature
- 850 hPa temperature
- 500 hPa geopotential

Month

May 2008

- May 2008
- Apr 2008
- Mar 2008
- Feb 2008
- Jan 2008
- Dec 2007
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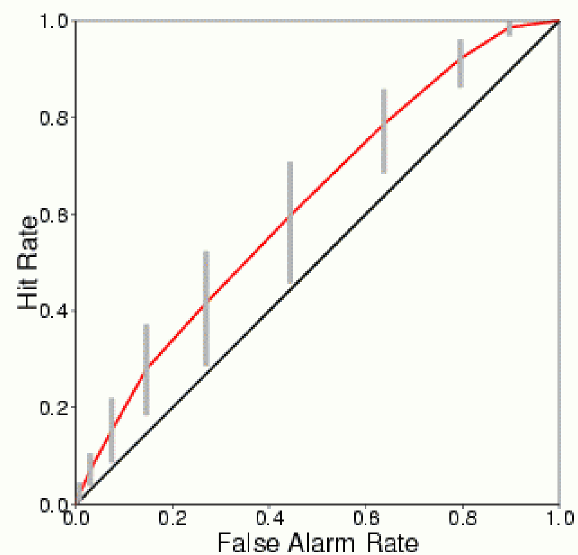
Lead time: one month lead time

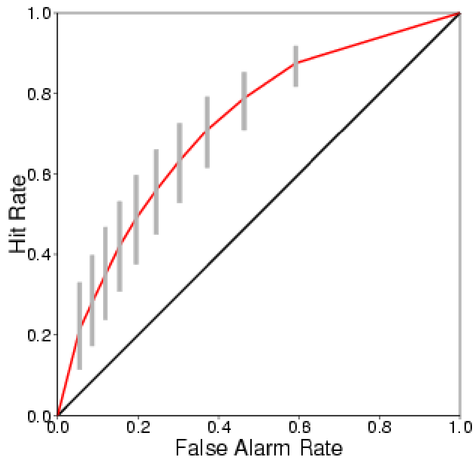
Area: Europe

Forecast type and skill measures: ROC for upper third of the distribution

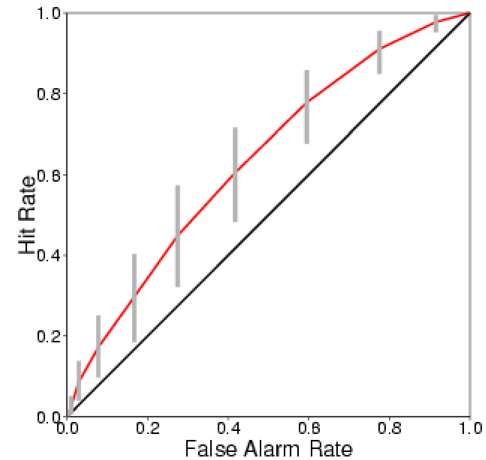
ROC diagram for ECMWF with 11 ensemble members
Near-surface temperature anomalies above the upper tercile
Accumulated over Europe (land points only)
Hindcast period 1981-2005 with start in May average over months 2 to 4
Skill scores and 95% conf. intervals (1000 samples)
ROC score: 0.620 (0.560, 0.680)



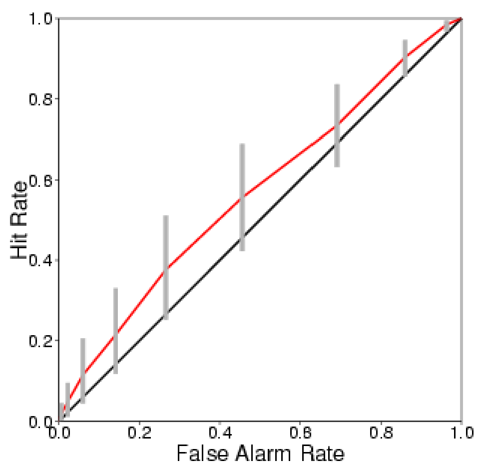
ROC diagram for ECMWF with 11 ensemble members
Near-surface temperature anomalies above the upper tercile
Accumulated over tropical band (land and sea points)
Hindcast period 1981-2005 with start in March average over months 2 to 4
Skill scores and 95% conf. intervals (1000 samples)
ROC score: 0.720 (0.660, 0.770)



ROC diagram for ECMWF with 11 ensemble members
Near-surface temperature anomalies above the upper tercile
Accumulated over North America (land points only)
Hindcast period 1981-2005 with start in March average over months 2 to 4
Skill scores and 95% conf. intervals (1000 samples)
ROC score: 0.640 (0.560, 0.700)



ROC diagram for ECMWF with 11 ensemble members
Near-surface temperature anomalies above the upper tercile
Accumulated over Europe (land points only)
Hindcast period 1981-2005 with start in March average over months 2 to 4
Skill scores and 95% conf. intervals (1000 samples)
ROC score: 0.570 (0.500, 0.640)



Summary (1):

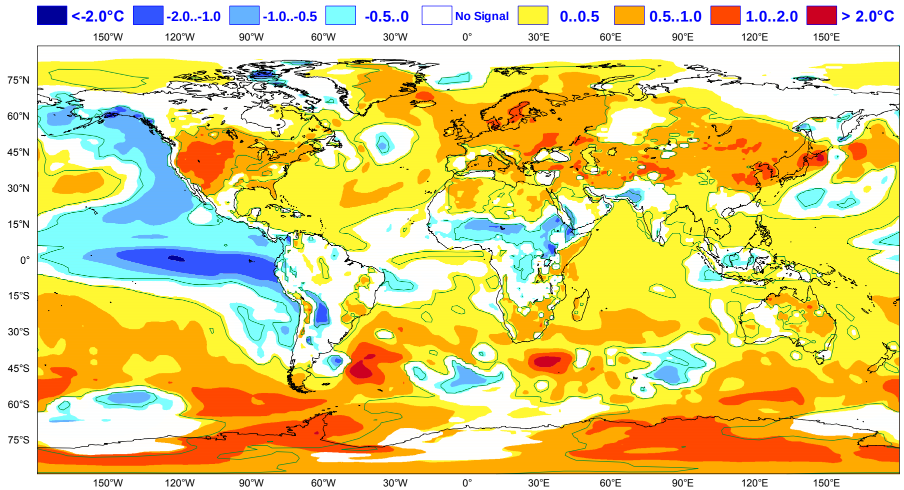
- **Seasonal fc. System-4 (S4):** IFS-NEMO coupled model, 3-D var. ocean data assimilation (NEMOVAR), higher atmos. spatial resolution than S3, larger ensemble size, extended re-forecast set.
- **Model biases**: much reduced extra-tropical biases, too strong trade winds and cold SST bias in the equatorial Pacific. ENSO SST variability is over-estimated.
- **SST forecast skill**: similar to S3 in the NINO regions (better in NINO3, slightly worse in NINO4), increased in the tropical and sub-trop. Atlantic.
- **Skill for atmospheric variables:** spatial averages of ensemble-mean scores are consistently higher than in S3 (NH summer better than winter).
- **Tropical atmospheric variability:** more realistic patterns of rainfall variability, better simulation of the interannual and decadal variation in tropical cyclone frequency.
- **Reliability:** the enhanced internal variability and better match between spread and error lead to more reliable seasonal forecasts w.r.t. S3 in both tropical and extra-tropical regions.

Summary (2)

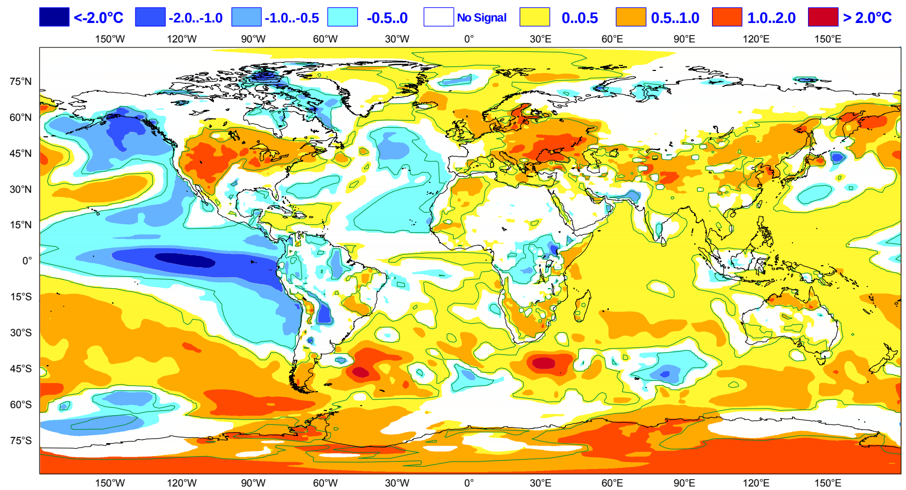
- The current operational seasonal forecast system provides a set graphic products on the web and digital data set to the users.
- The ECMWF seasonal forecast is a good system for El Nino predictions.
- Seasonal forecast predictions, particularly over mid-latitudes, should be used in combination with some estimate of the forecast skill. Various skill estimates are available to the users.
- Multi-model approach: a way to deal with model error (model calibration) and to enhance forecast reliability.
- For further reading see ECMWF Tech Memo N.656, available at http:// www.ecmwf.int/publications

S3 tends to persist the spring conditions in the Subtropical Atlantic

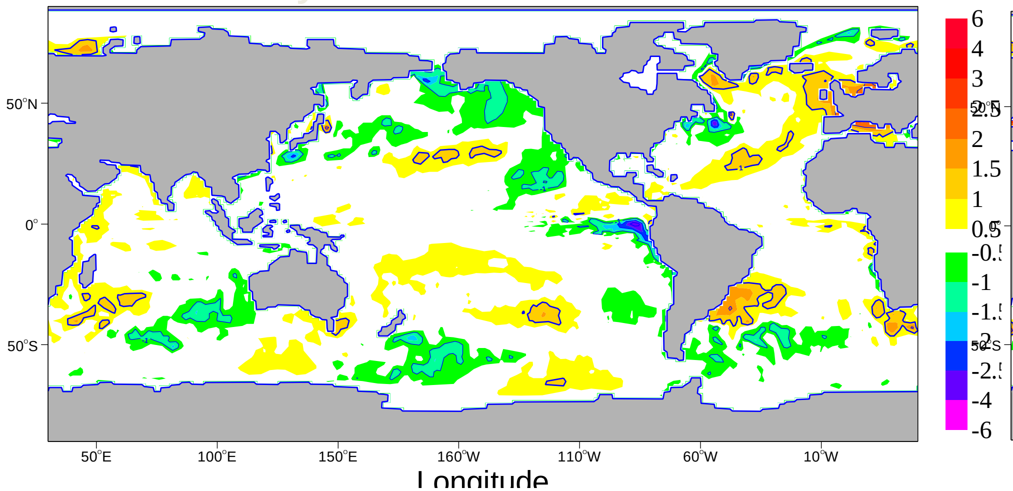
JAS T2m from 1st of May



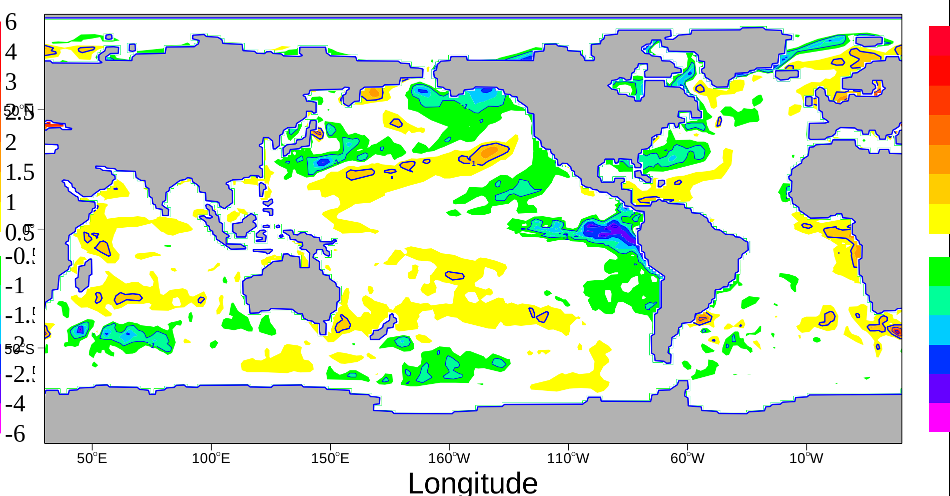
JAS T2m from 1st of June



May SST Initial Conditions



June SST Initial Conditions



Outlook for Europe

Long-term predictions over Europe are particularly difficult:

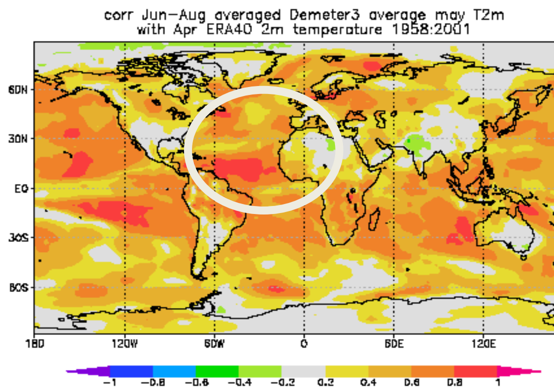
• At times during very large El Niño part of Europe seem to be affected.

• However non-linearity of the atmosphere seem to play a relevant role over this region.

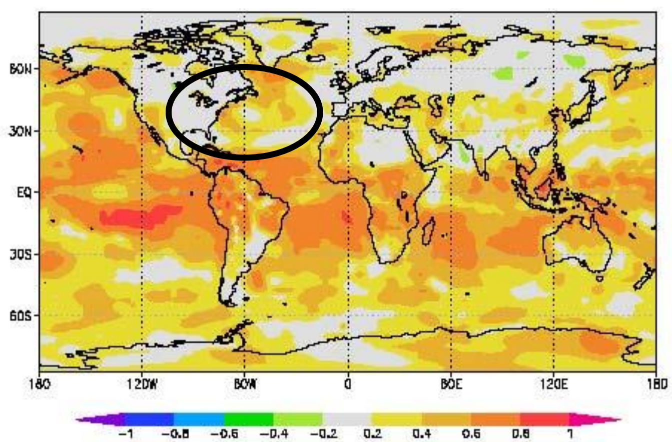
• The Atlantic Ocean influence on the weather over Europe is not yet well understood.

Persistence and mixed layer depth

Persistence from April to JJA

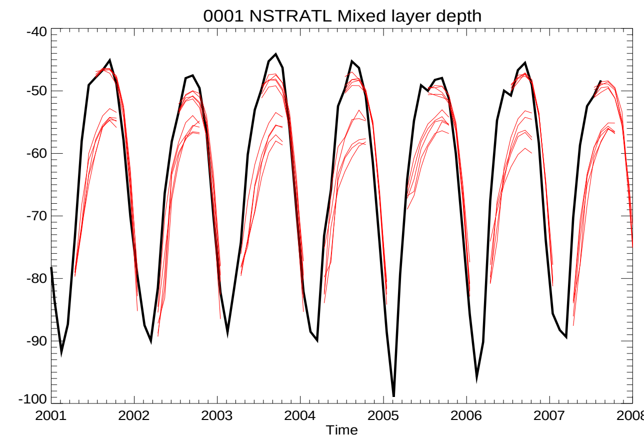


ERA-40



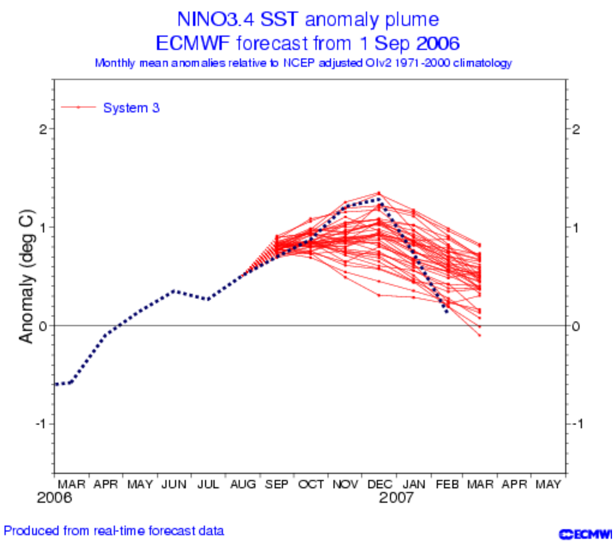
MLD in North Subtropical Atlantic

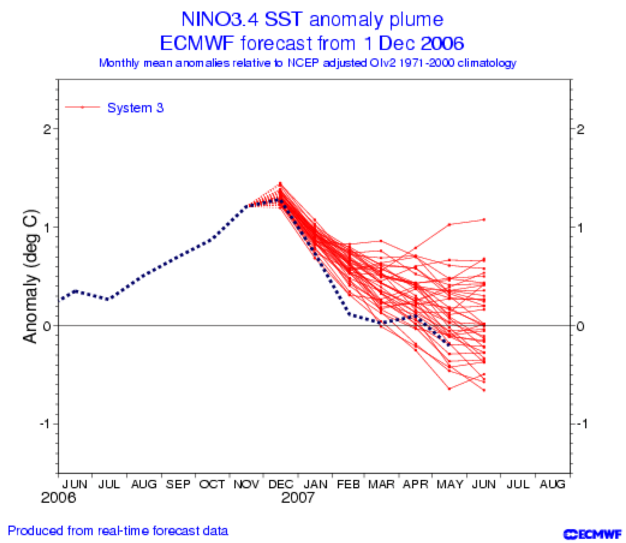
Apr and July starts

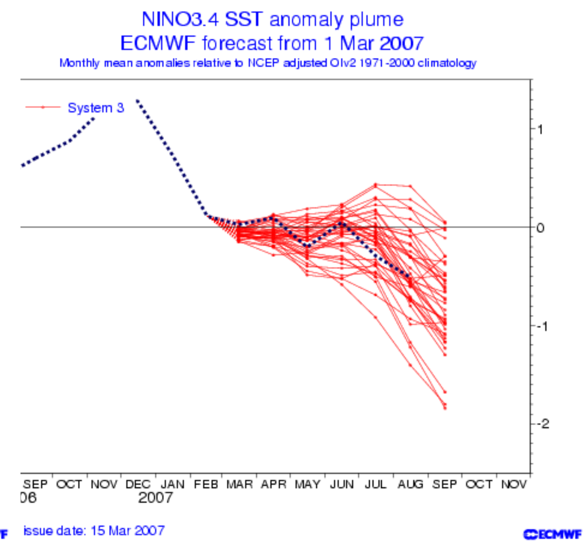


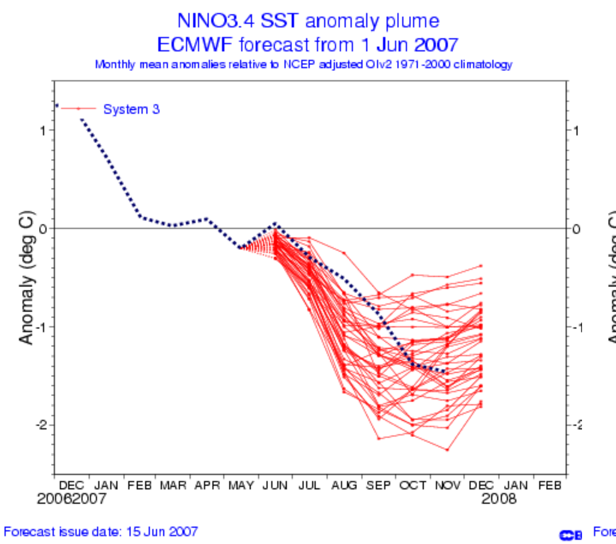
- Persistence (from spring to summer) in coupled models is too large in the North-Subtropical Atlantic
- The couple model can not predict the rapid shallowing of the mixed layer from spring to summer.

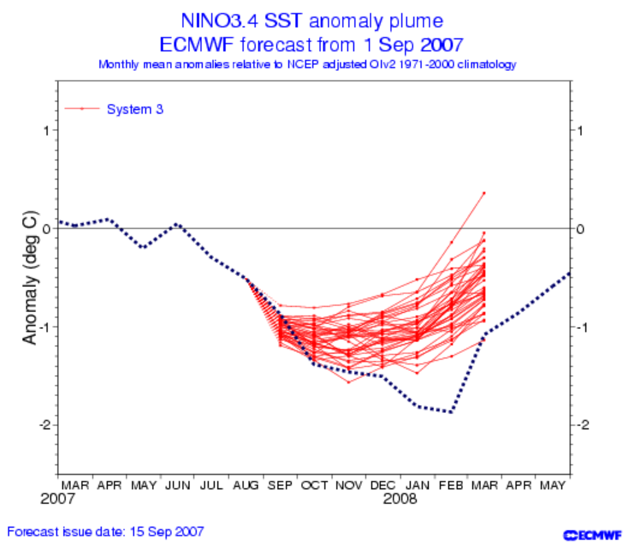
Nino 3.4 past forecasts:

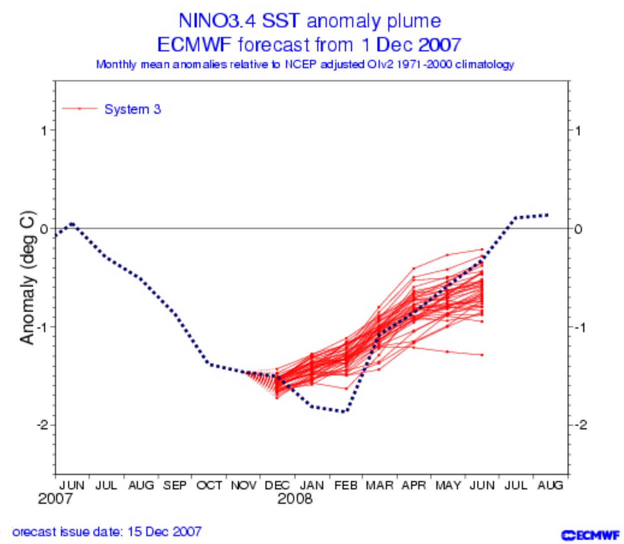




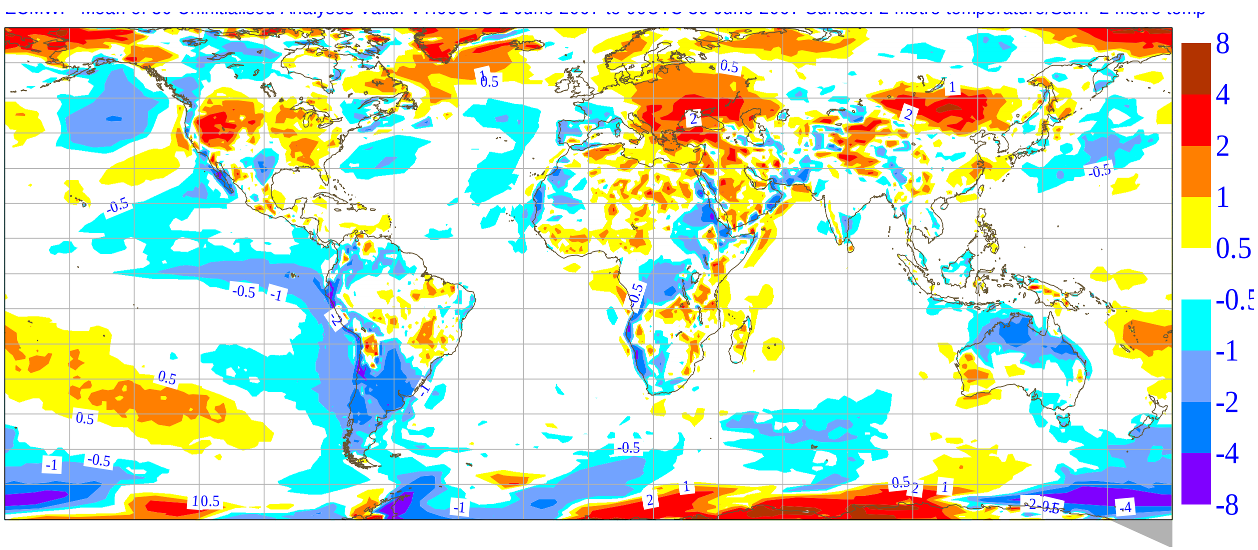


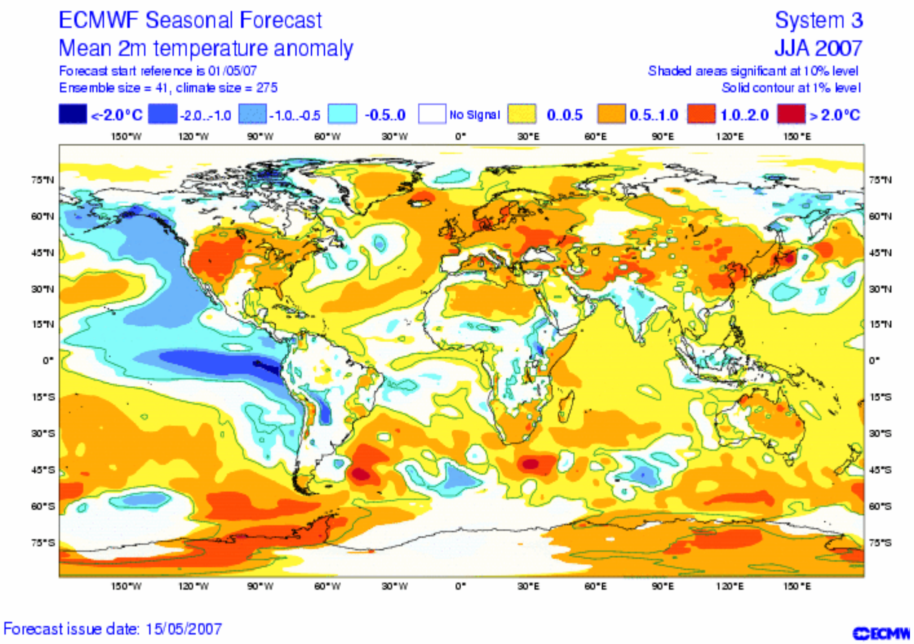


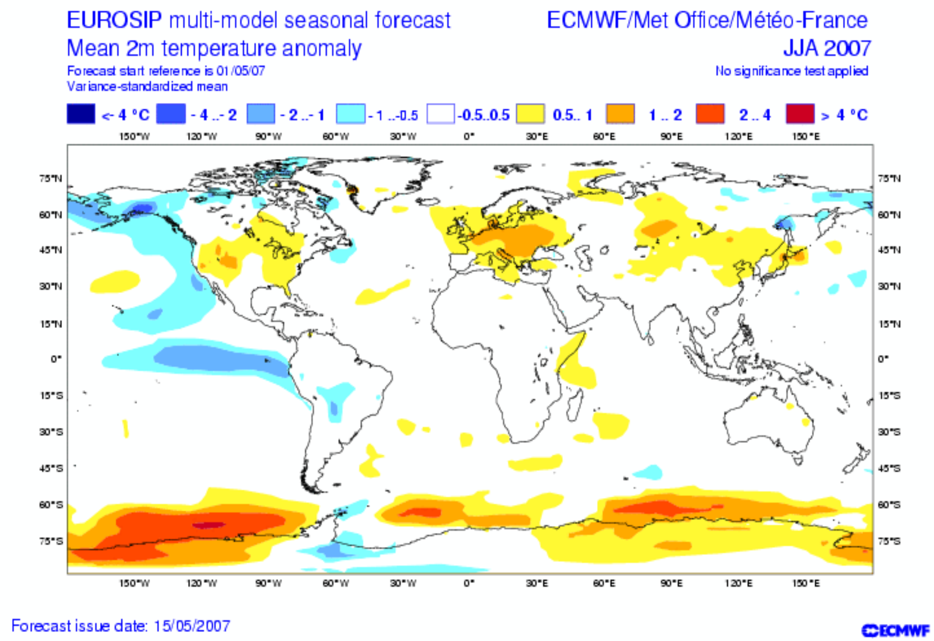




JJA 2007 2mt anomalies



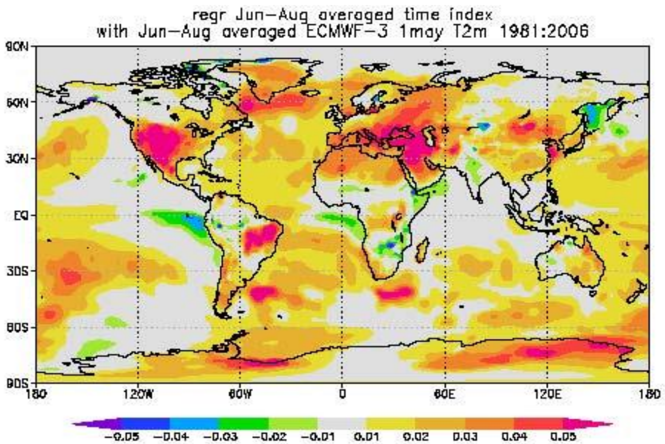


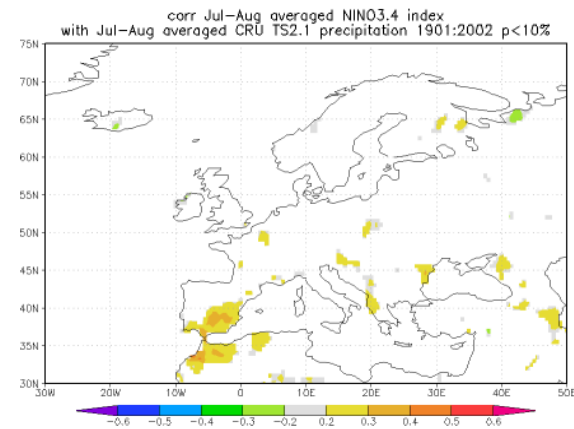


Climate trends, La Nina, or others?

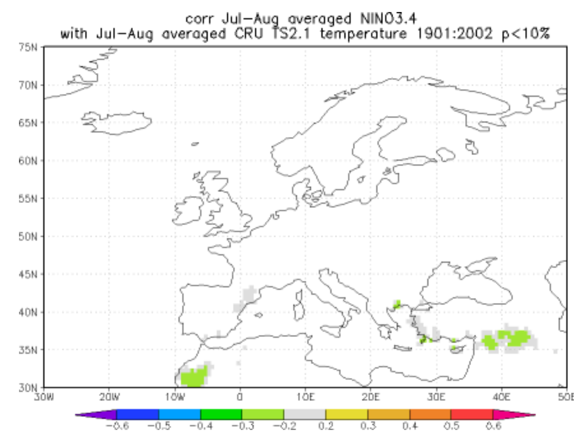
T2m linear trends in S3

El Nino Teleconnections





Precip



T2m

- Warming in Central/Eastern Europe is part of the linear trends.
- From the linear teleconnections, La Nina is unlikely to be responsible for the anomalous precipitation and T2m during summer of 2007 in Western Europe.

From van Oldenborgh 2007