

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: twice daily
51 members, 30/60 km 91levels, to 15 days ahead
- Extended range forecasts /ENS extension: twice a week (Mon/Thursdays)
51 members, 30/60 km 91 levels, to 1 month ahead
- **Long range forecasts: once a month (coupled to ocean model)
members, ~80 km 91 levels, to 7 months ahead**

Long range forecasts provide information about atmospheric and oceanic conditions averaged over the next few months.

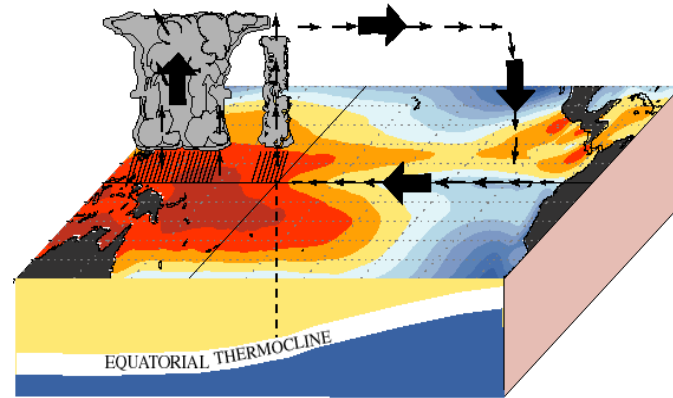
Despite the chaotic nature of the atmosphere, long term predictions rely on a number of components which themselves show variations on long time scales (seasons and years) and, to a certain extent, are predictable.

The most important of these components is the **ENSO (El Nino Southern Oscillation) cycle. Although ENSO is a coupled ocean-atmosphere phenomenon centred over the tropical Pacific it affect atmospheric circulation over remote regions.**

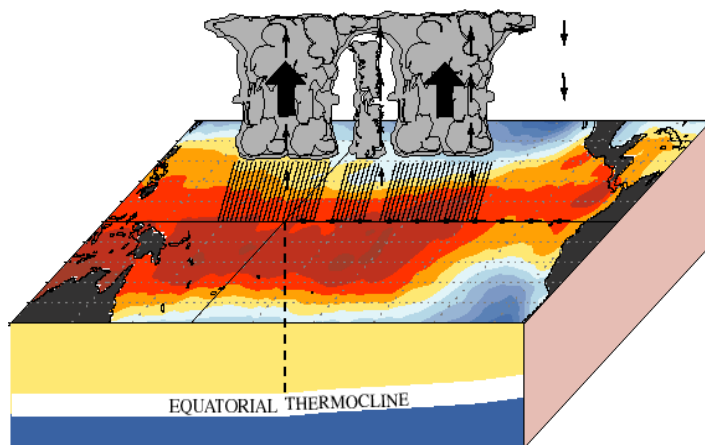
- **ENSO variability**
- **Other tropical ocean SST**
- **Climate change** - long term trends
- **Land surface conditions** - e.g. soil moisture in 2003, sea-ice

THE EL NIÑO/SOUTHERN OSCILLATION (ENSO) CYCLE

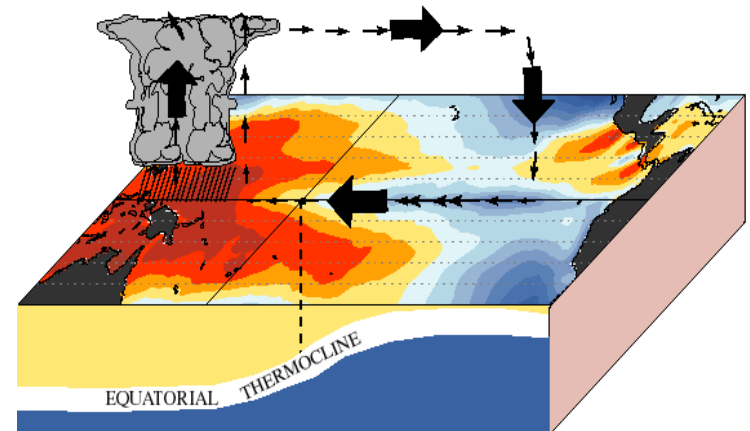
December - February Normal Conditions



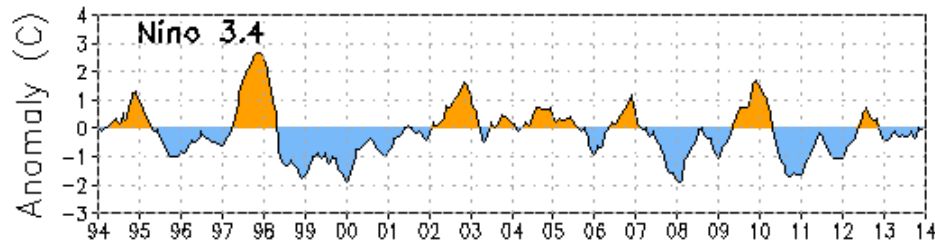
December - February El Niño Conditions



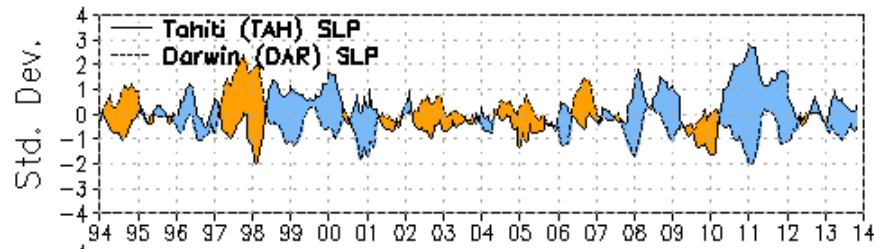
December - February La Niña Conditions



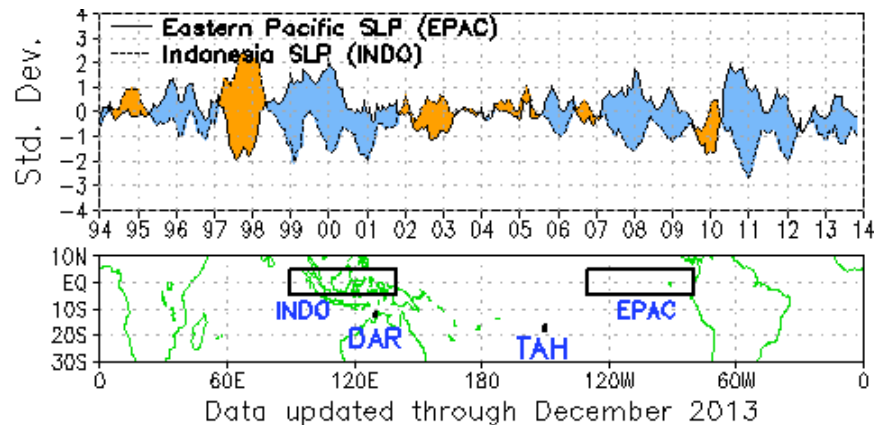
Sea Surface Temperature (SST) anomalies over the Equatorial Pacific:



Southern Oscillation Index (SOI):

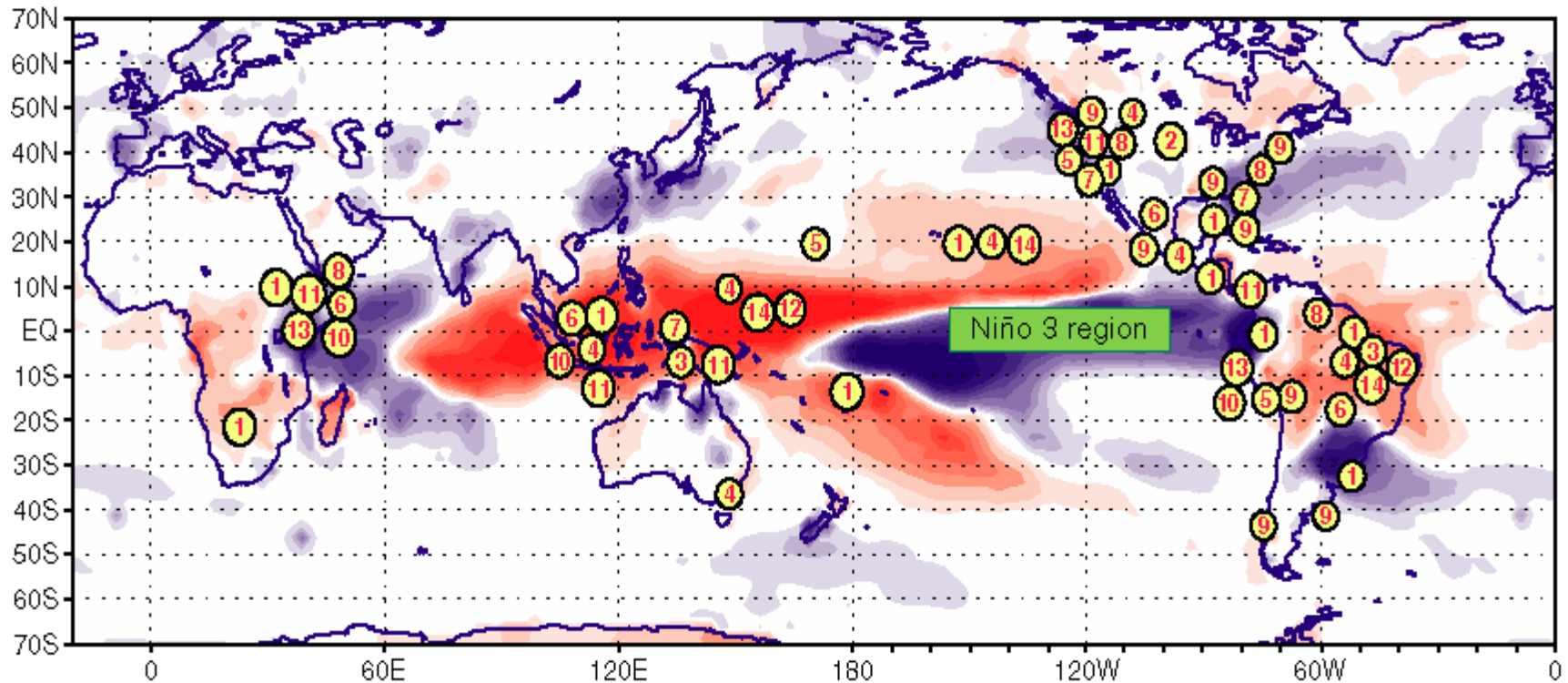


Equatorial Southern Oscillation Index (SOI):



Weather-related natural disasters

Societal Impacts from 1997/98 El Niño



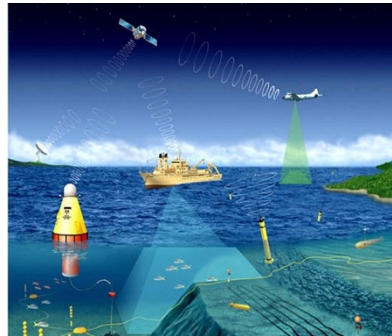
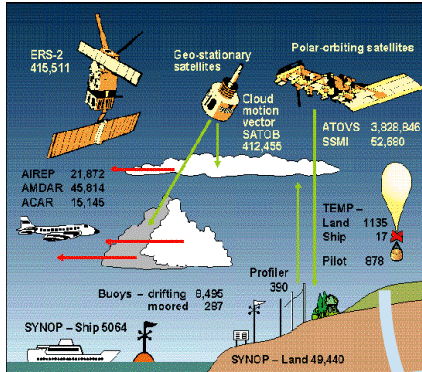
- | | | | |
|----------------------|-------------------------|-----------------------------|-------------------------|
| 1. Crop/Stock Damage | 5. Fisheries Disruption | 9. Property Damage | 13. Wildlife Fatalities |
| 2. Energy Savings | 6. Health Risks | 10. Tourism Decreased | 14. Water Rationing |
| 3. Famine | 7. Human Fatalities | 11. Transportation Problems | |
| 4. Fires | 8. Pests Increased | 12. Social Disruptions | |



Climate Prediction Center

ECMWF Seasonal Forecasting System

Observations



Data Assimilation

Current state of the atmosphere

Current state of the ocean

Coupled model

Atmospheric model

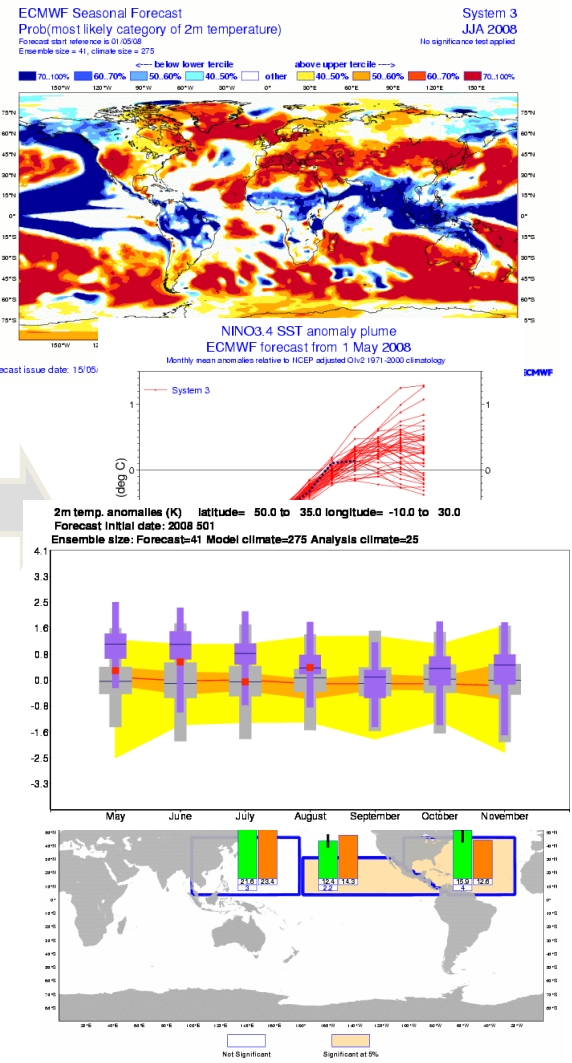


Coupler



Ocean Model

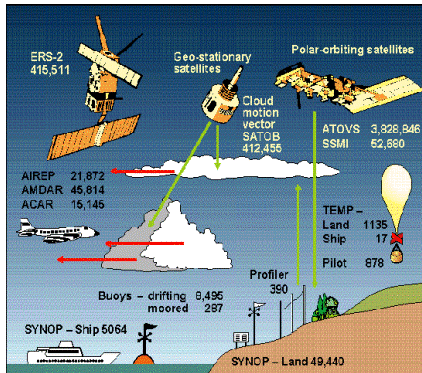
Forecast Products



Initialization:

Data Assimilation

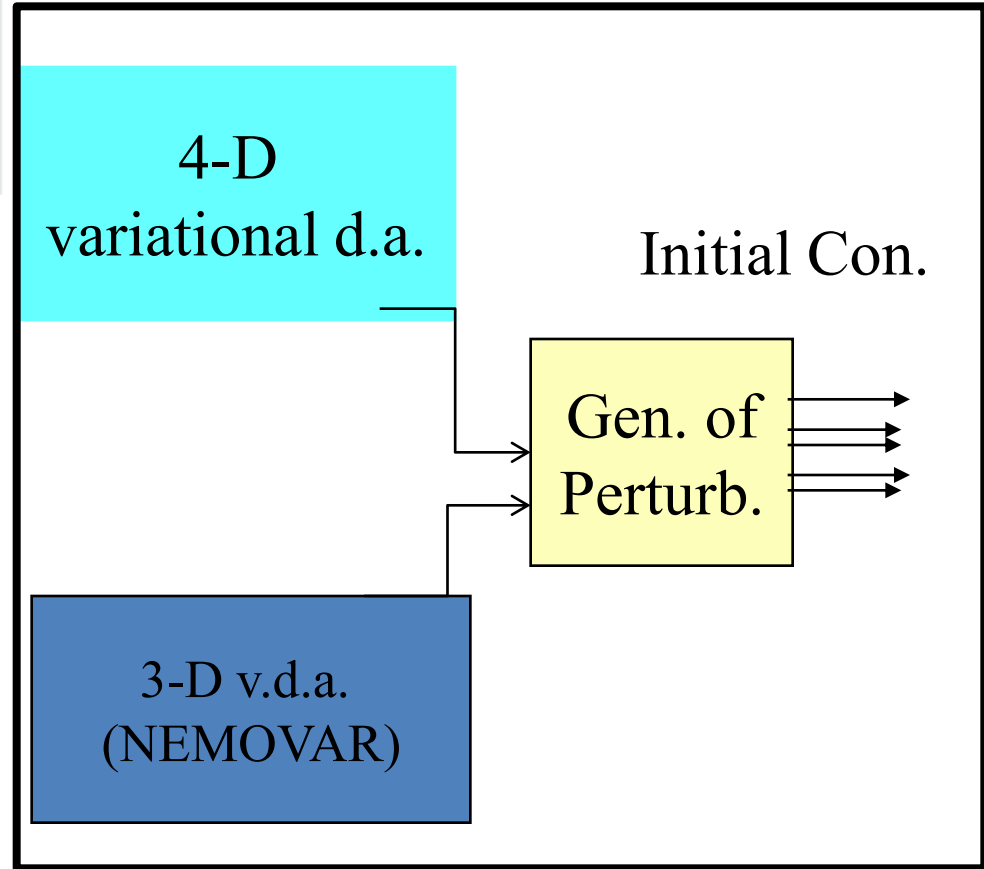
Observations



Current state of the atmosphere

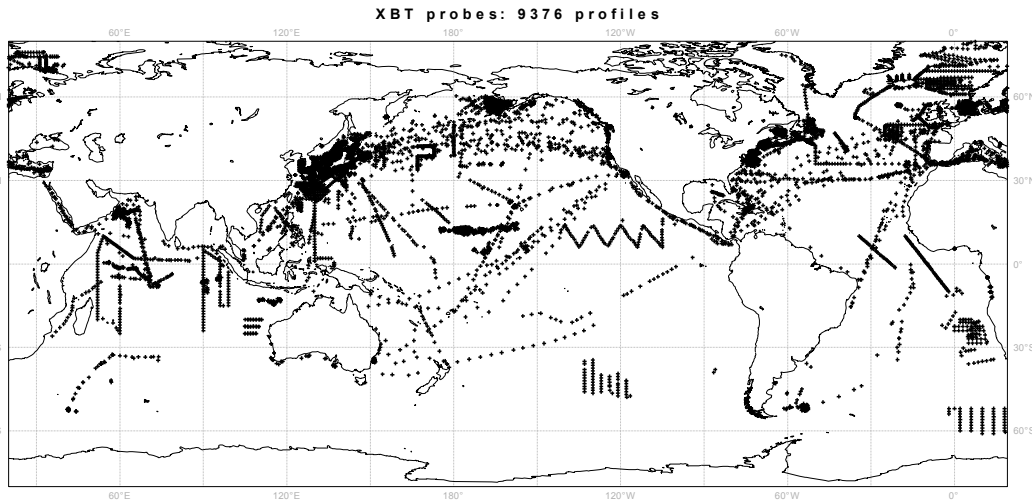
Current state of the ocean

System 4



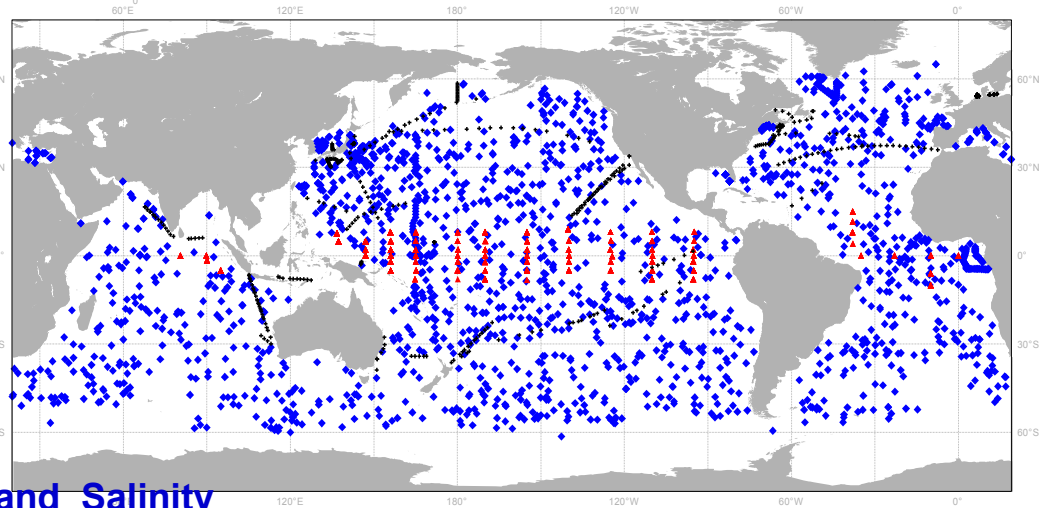
Ocean Observing System

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

11/02/2014

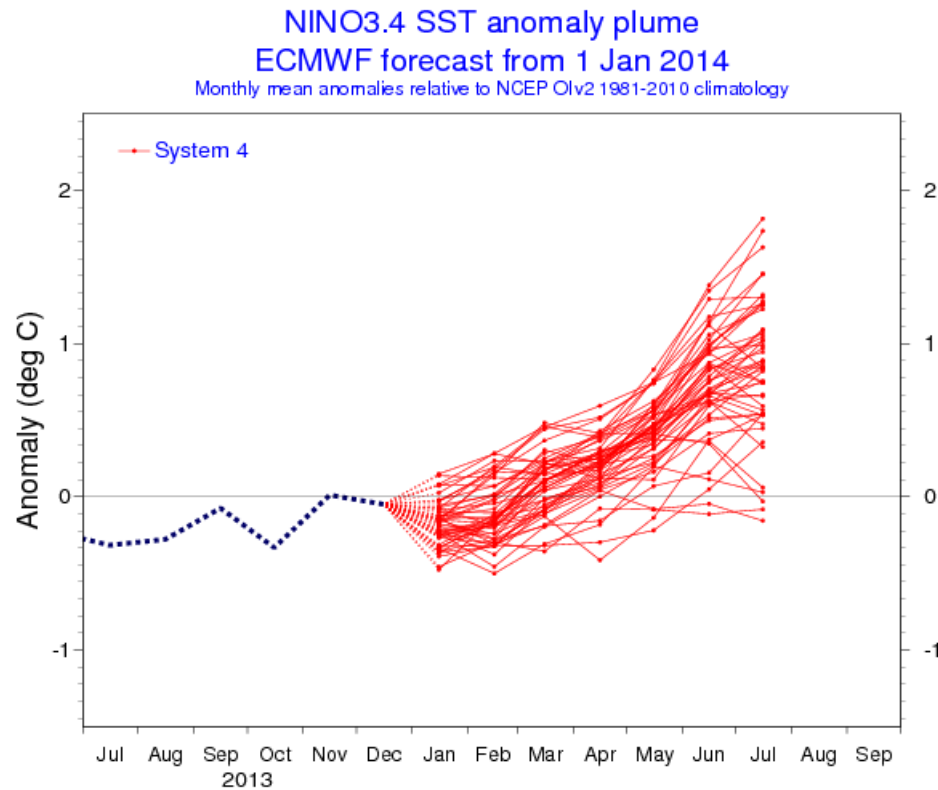
ECMWF System 4: main features

- **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**

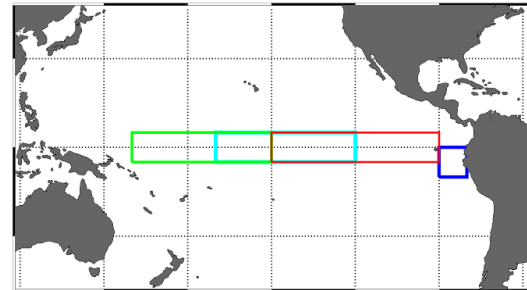
Products :

- Ocean Analysis
- Seasonal outlook: (up to 7 months ahead)
 - Forecasts for Nino3, Nino3.4 and Nino4
 - Spatial plots (ens.mean anomaly, terciles ..)
 - Climagrams (similar to Epsgrams, teleconenction patterns)
 - Tropical storms

NINO3.4 plumes



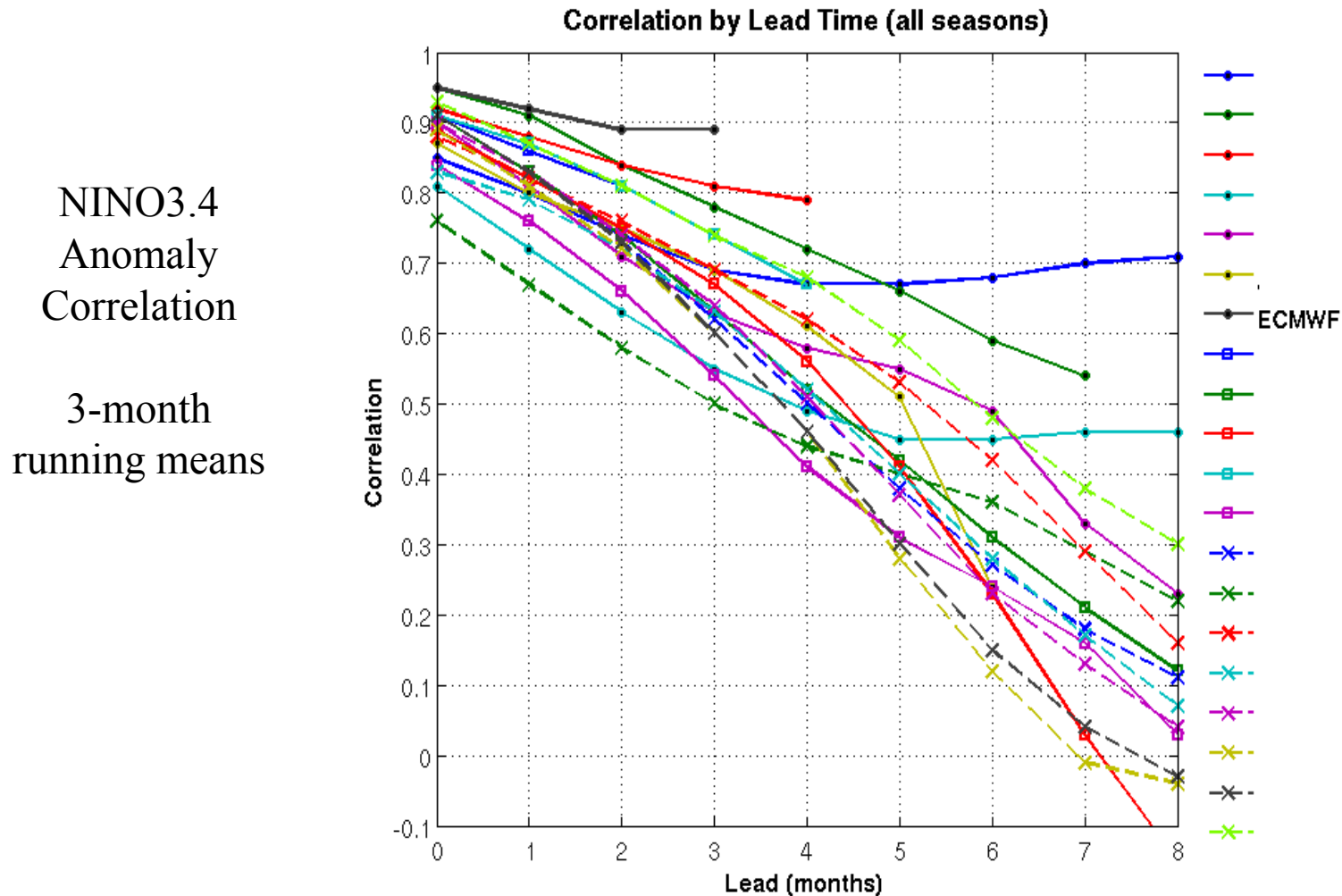
Nino3.4, Lon = [-170, -120], Lat = [-5, 5]
Nino12, Lon = [-90, -80], Lat = [-10, 0]
Nino4, Lon = [160, -150], Lat = [-5, 5]
Nino3, Lon = [-150, -90], Lat = [-5, 5]



ECMWF

Forecast is made available on the 8h of each month

ENSO skill: comparison with other seasonal fc. systems



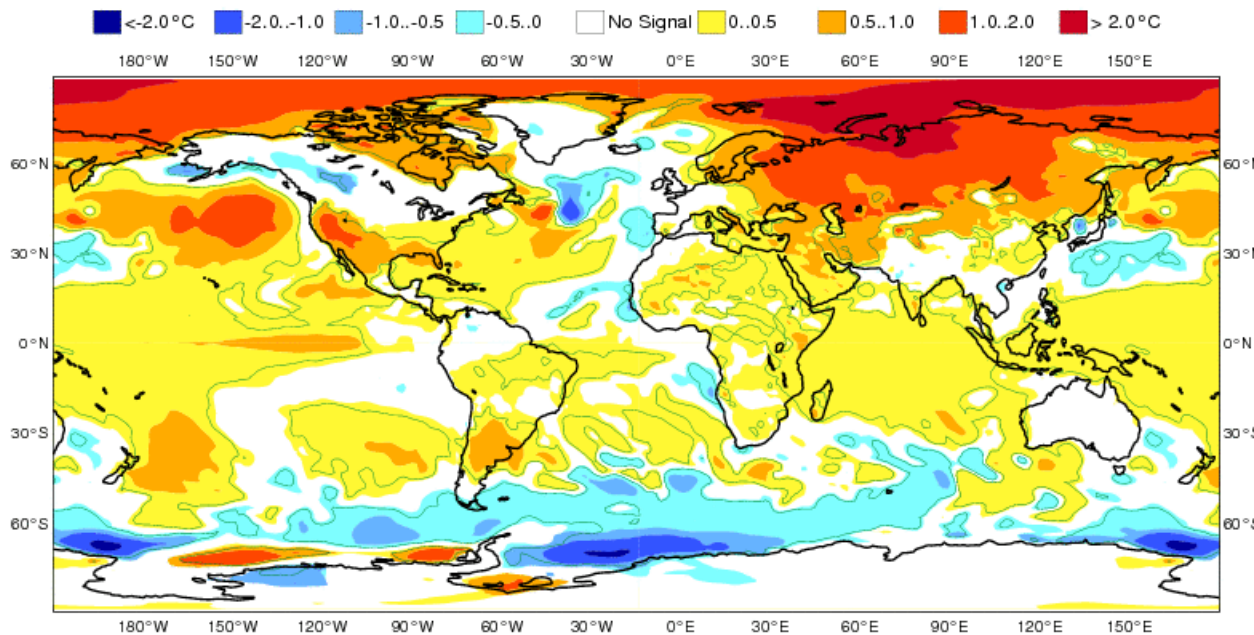
From: Barnston et al. 2011: Skill of Real-time Seasonal ENSO Model Predictions during 2002-2011—Is Our Capability Increasing? BAMS, accepted

Seasonal forecast charts :

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

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

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



Available parameters are:

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

Seasonal forecast charts :

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

ECMWF Seasonal Forecast

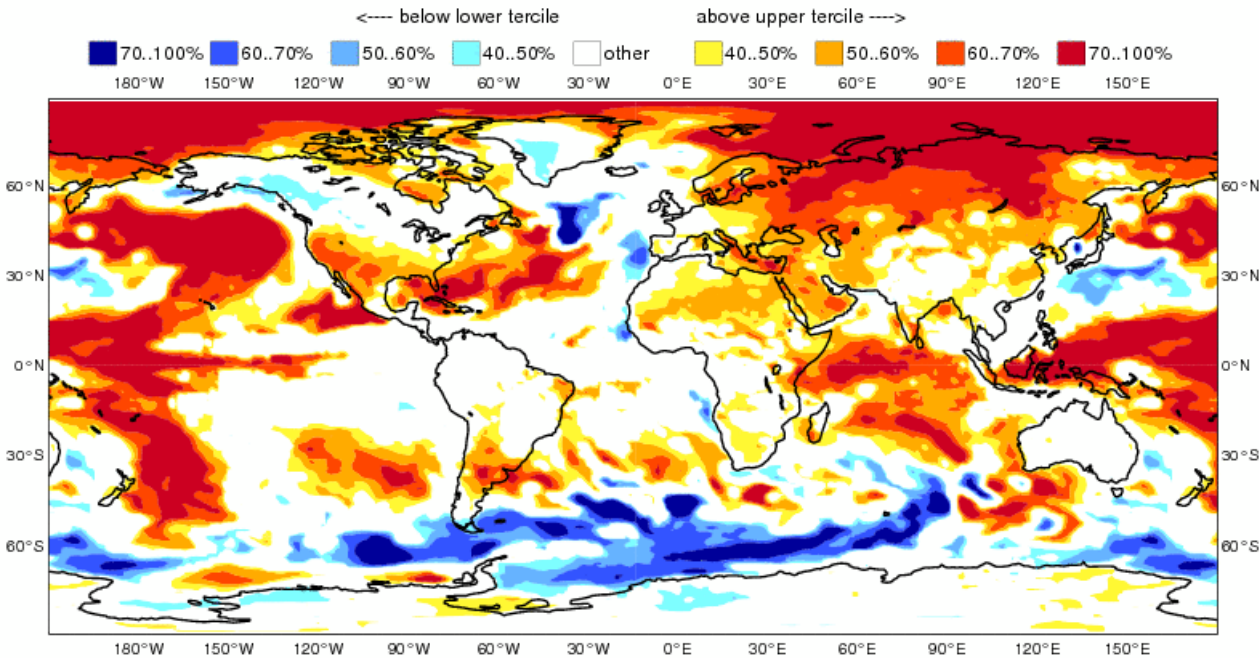
Prob(most likely category of 2m temperature)

Forecast start reference is 01/01/14

Ensemble size = 51, climate size = 450

System 4

MAM 2014



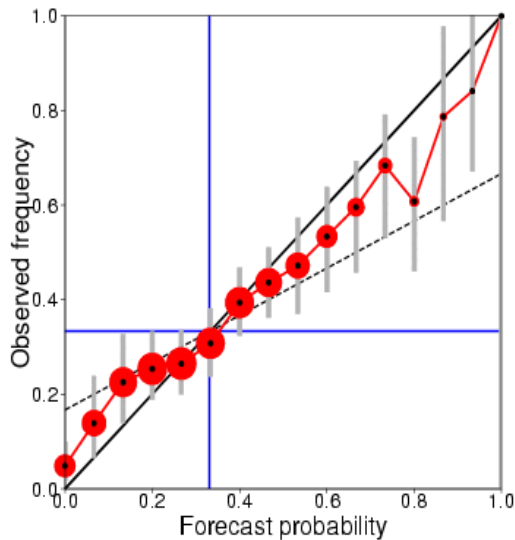
Available parameters are:

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

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

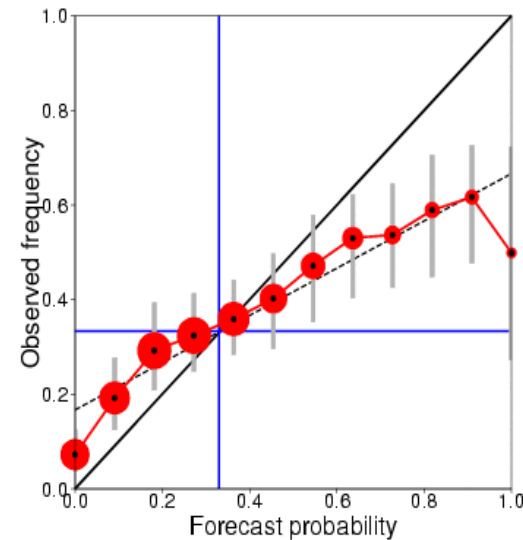
Sys 4

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)



Sys 3

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

Lead time: two months lead time
 Area: Global
 Forecast type and skill measures: tercile summary

ECMWF Seasonal Forecast
 Prob(most likely category of 2m temper...
 Forecast start reference is 01/01/14
 Ensemble size = 51, climate size = 450

Month

- Jan 2014
- Jan 2014
- Dec 2013
- Nov 2013
- Oct 2013
- Sep 2013
- Aug 2013

Your Room

Add this product

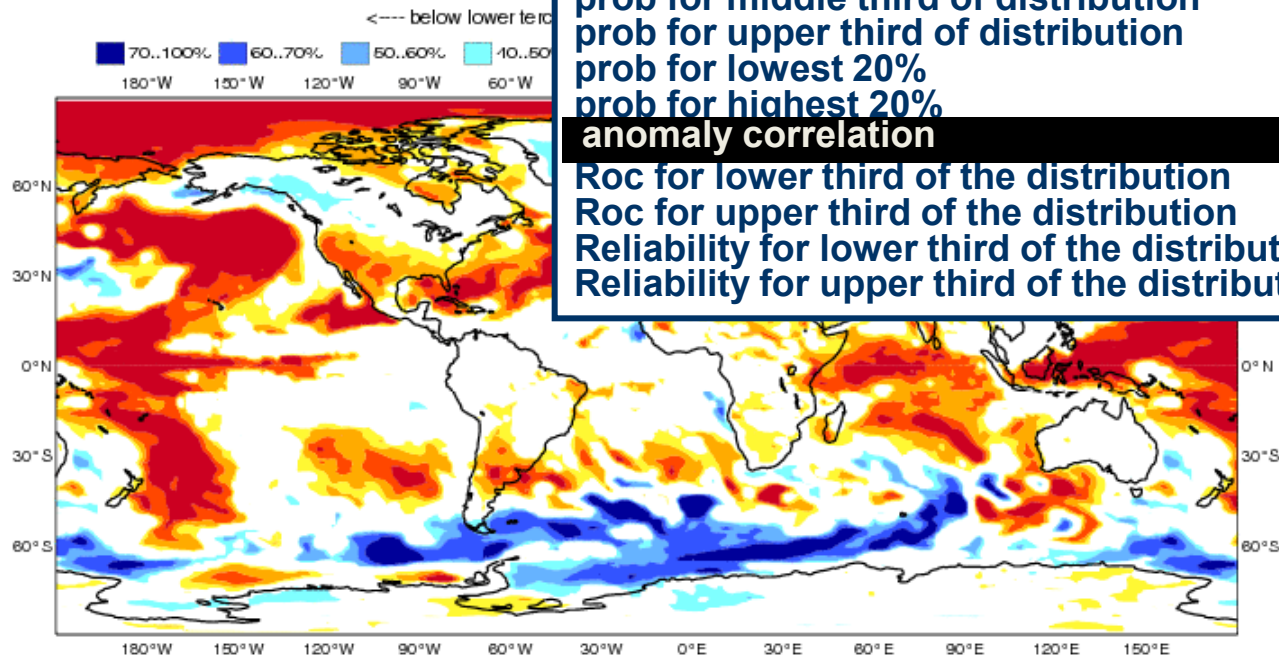
Show overview

- Lead time
- Area
- Month
- Forecast type and skill measures

Download...

- PDF (613.2 Kbytes)
- Postscript (1.2 Mbytes)

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

Month

- Jan 2014
- Jan 2014**
- Dec 2013
- Nov 2013
- Oct 2013
- Sep 2013
- Aug 2013
- ...

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Show overview

- Lead time
- Area
- Month
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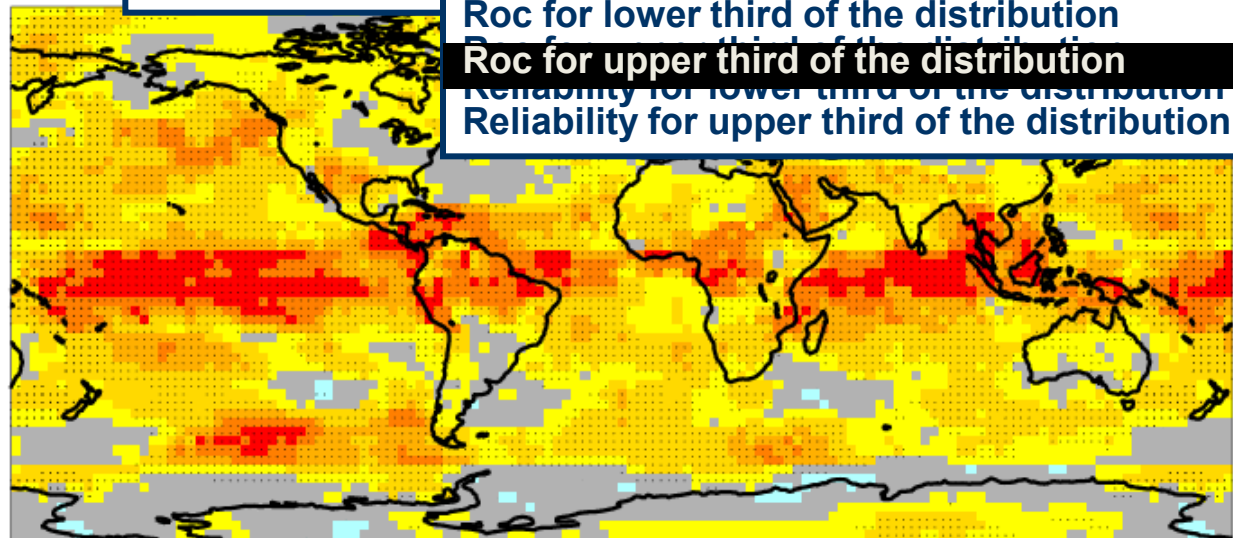
- 11/02/2014
- PDF (344.3 Kbytes)
- Postscript (373.3 Kbytes)

Lead time: Area: Forecast type and skill measures:

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

- 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

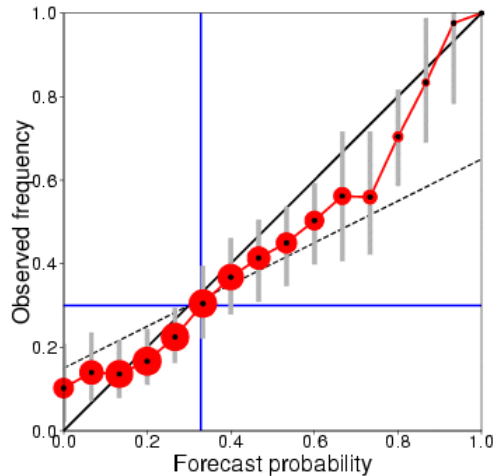
Anomaly Co
Near-surfac
Hindcast pe
Black dots f



Reliability for summer predictions: warm events

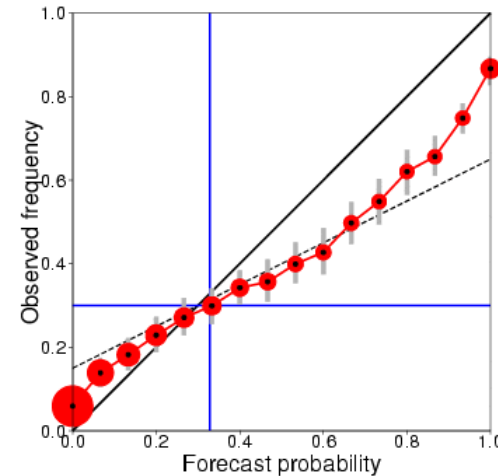
Europe

Reliability diagram for ECMWF with 15 ensemble members
Near-surface air temperature anomalies below the lower 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: 0.108 (0.009, 0.183)
Reliability skill score: 0.980 (0.921, 0.991)
Resolution skill score: 0.128 (0.072, 0.203)



Tropics

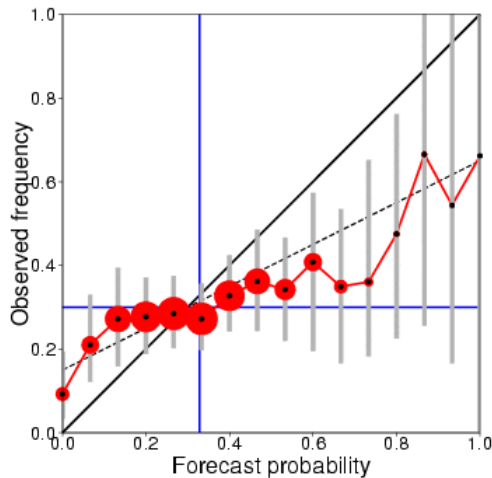
Reliability diagram for ECMWF with 15 ensemble members
Near-surface air temperature anomalies below the lower tercile
Accumulated over tropical band (land and sea points)
Hindcast period 1981-2010 with start in May average over months 2 to 4
Skill scores and 95% conf. intervals (1000 samples)
Brier skill score: 0.214 (0.146, 0.279)
Reliability skill score: 0.949 (0.925, 0.965)
Resolution skill score: 0.266 (0.211, 0.322)



Reliability for winter predictions : cold event

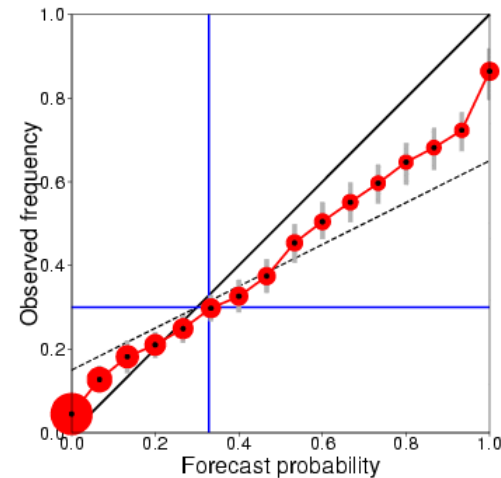
Europe

Reliability diagram for ECMWF with 15 ensemble members
Near-surface air temperature anomalies below the lower tercile
Accumulated over Europe (land and sea points)
Hindcast period 1981-2010 with start in November average over months 2 to 4
Skill scores and 95% conf. intervals (1000 samples)
Brier skill score: -0.053 (-0.177, 0.032)
Reliability skill score: 0.929 (0.810, 0.969)
Resolution skill score: 0.018 (0.008, 0.068)



Tropics

Reliability diagram for ECMWF with 15 ensemble members
Near-surface air temperature anomalies below the lower tercile
Accumulated over tropical band (land and sea points)
Hindcast period 1981-2010 with start in November average over months 2 to 4
Skill scores and 95% conf. intervals (1000 samples)
Brier skill score: 0.248 (0.175, 0.311)
Reliability skill score: 0.964 (0.942, 0.978)
Resolution skill score: 0.284 (0.225, 0.338)

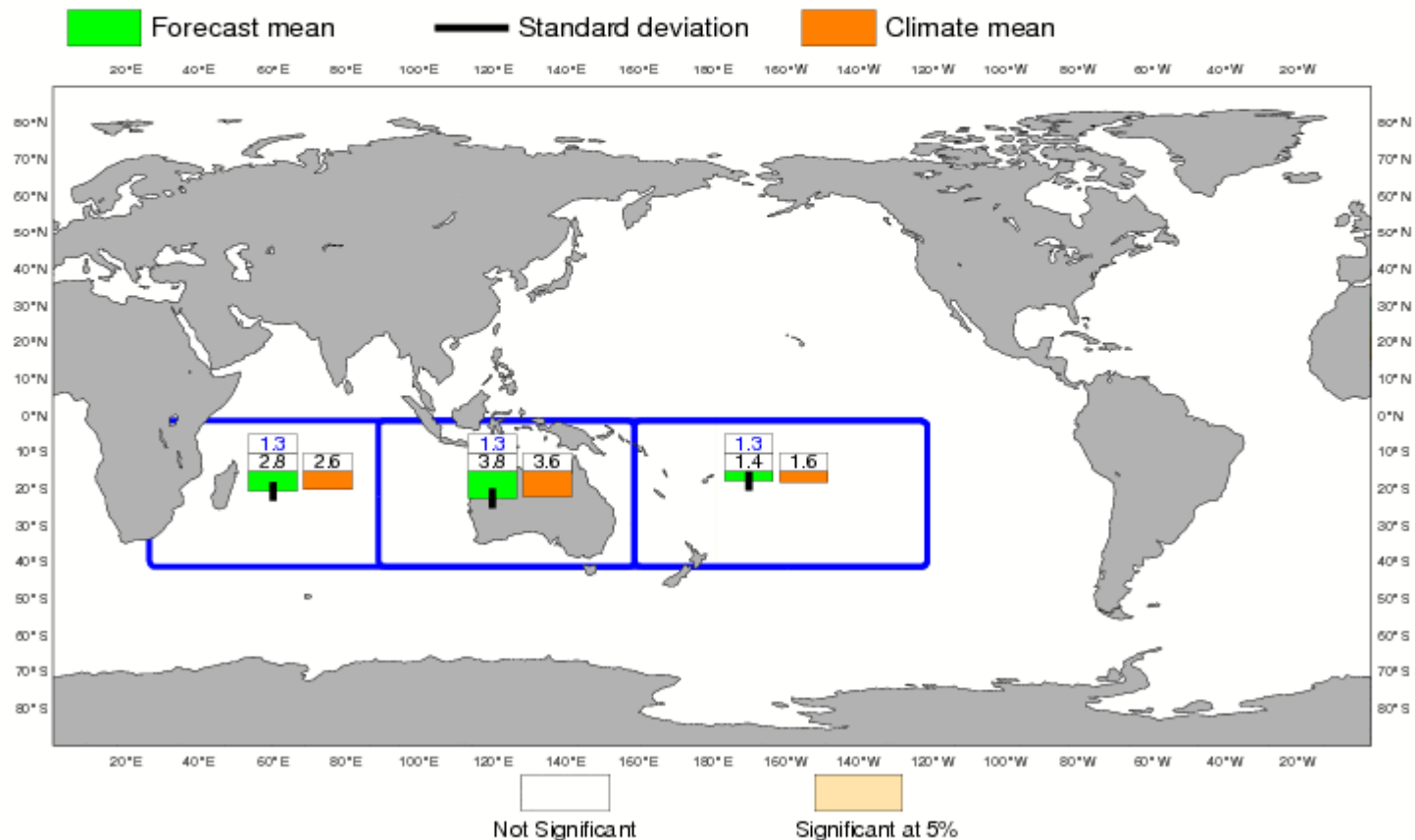


ECMWF Seasonal Forecast Hurricane or typhoon Frequency

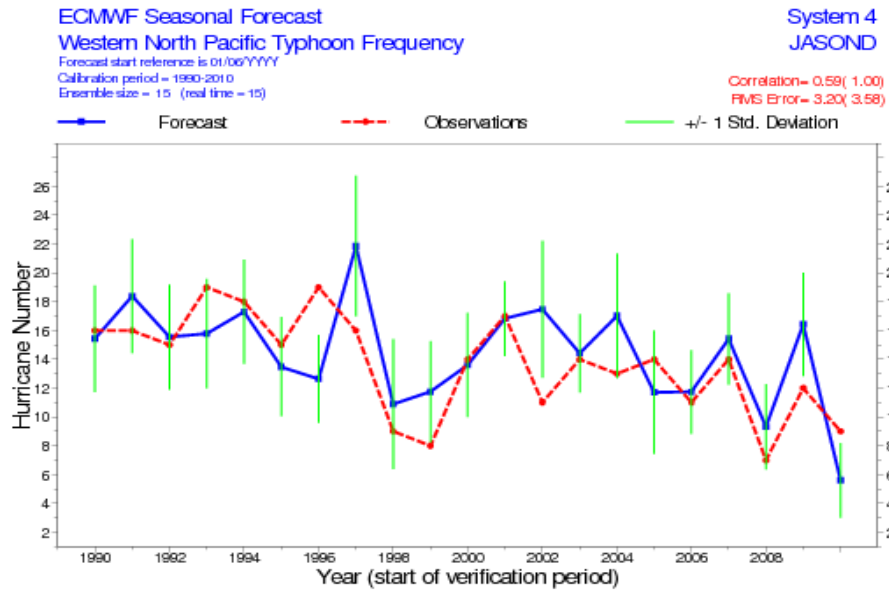
Forecast start reference is 01/01/2014
Ensemble size = 51, climate size = 300

System 4
FMAMJJ 2014

Climate (initial dates) = 1990-2009



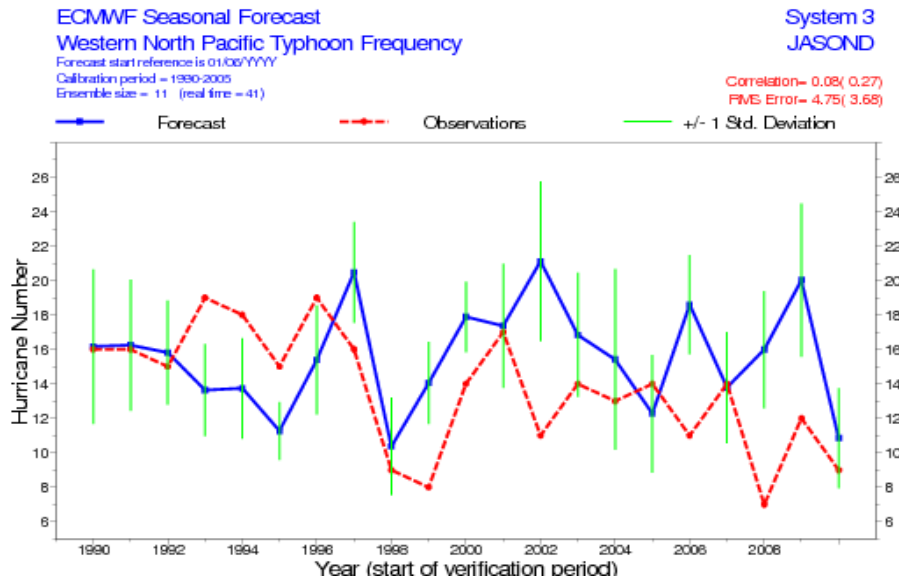
Prediction of tropical cyclone frequency: NW Pacific



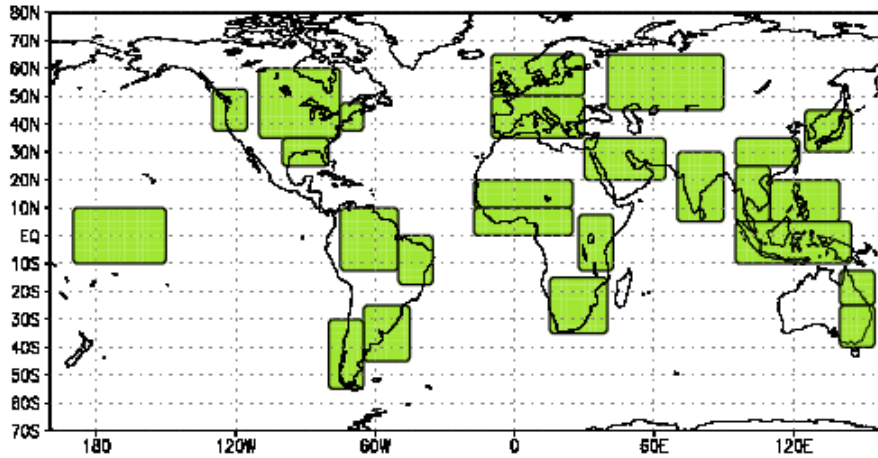
System 4
vs. ERA-Int.

July-Dec.
1990-2010

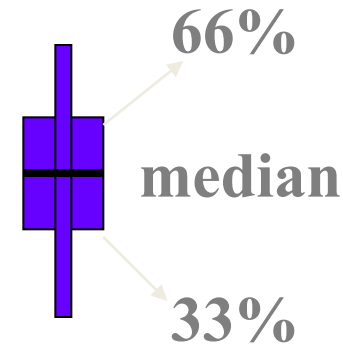
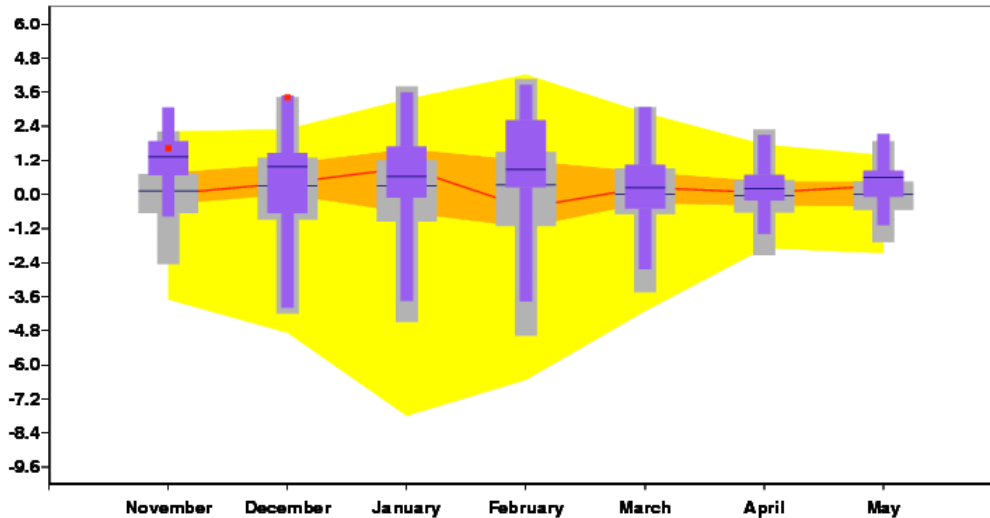
System 3
vs. ERA-Int.



Climagrams : temp. area averages

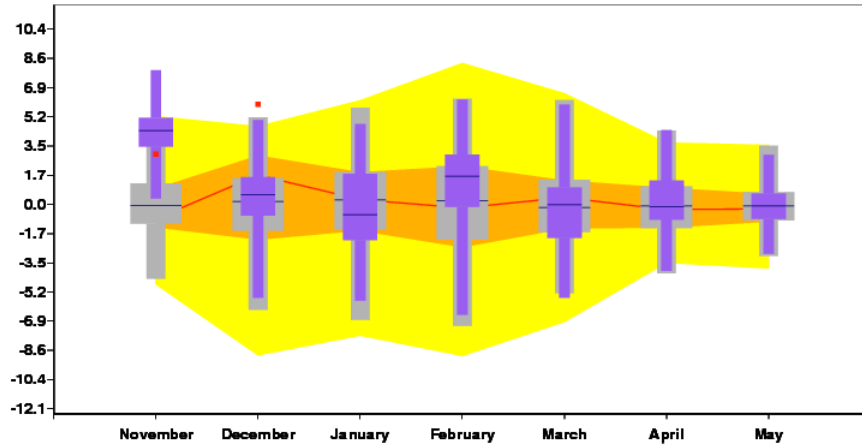


2m temp. anomalies (K) latitude= 65.0 to 50.0 longitude= -10.0 to 30.0
 Forecast initial date: 20131101
 Ensemble size: Forecast=51 Model climate=450 Analysis climate=30

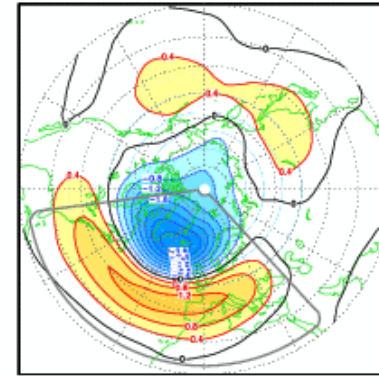


Climagrams : teleconnections indices NAO

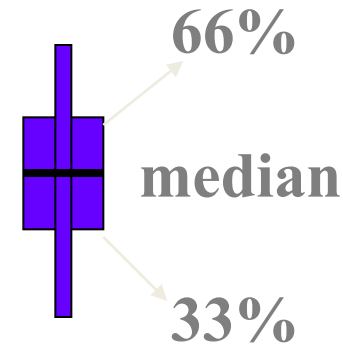
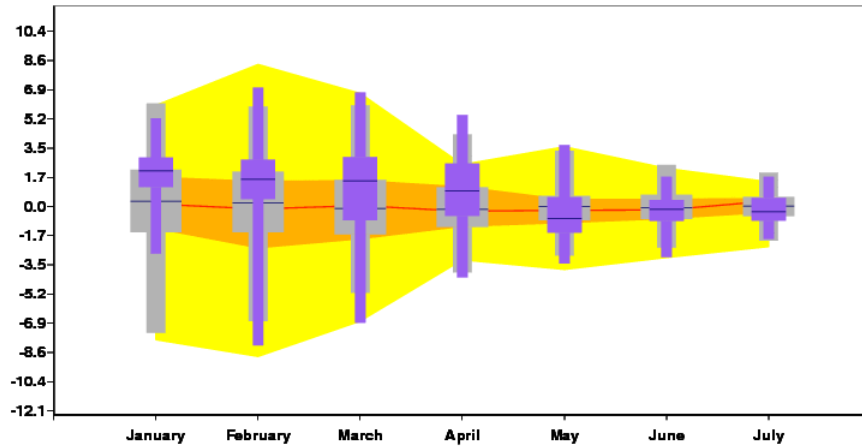
North Atlantic Oscillation
 Forecast initial date: 20131101
 Ensemble size: Forecast=51 Model climate=450 Analysis climate=30



eof 1: North Atlantic Oscillation (NAO)



North Atlantic Oscillation
 Forecast initial date: 2014 101
 Ensemble size: Forecast=51 Model climate=450 Analysis climate=30

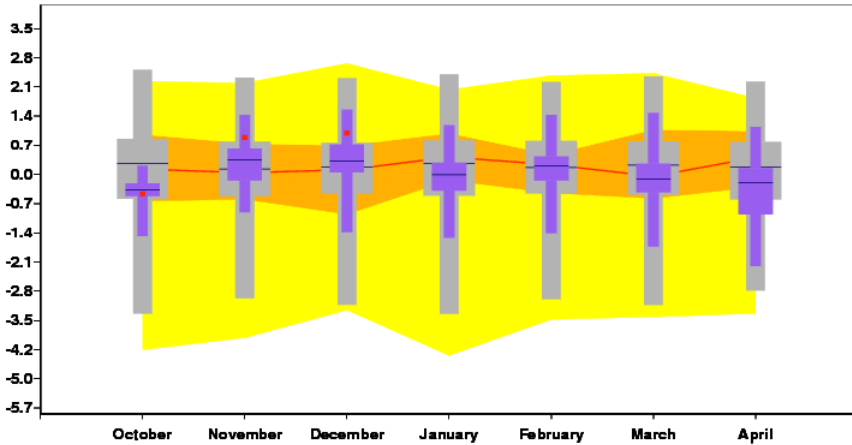


Climagrams : teleconnections indices SOI

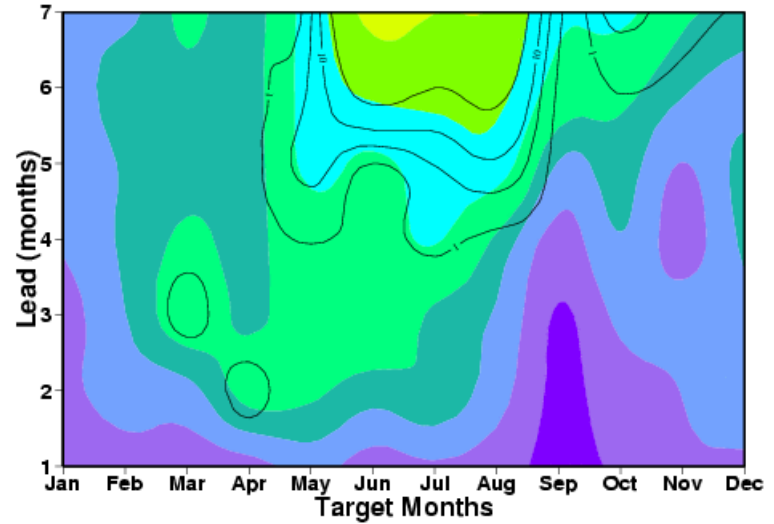
Equatorial Southern Oscillation

Forecast initial date: 20131001

Ensemble size: Forecast=51 Model climate=450 Analysis climate=30



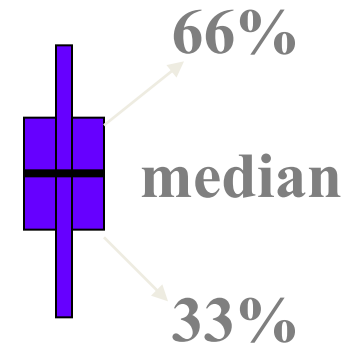
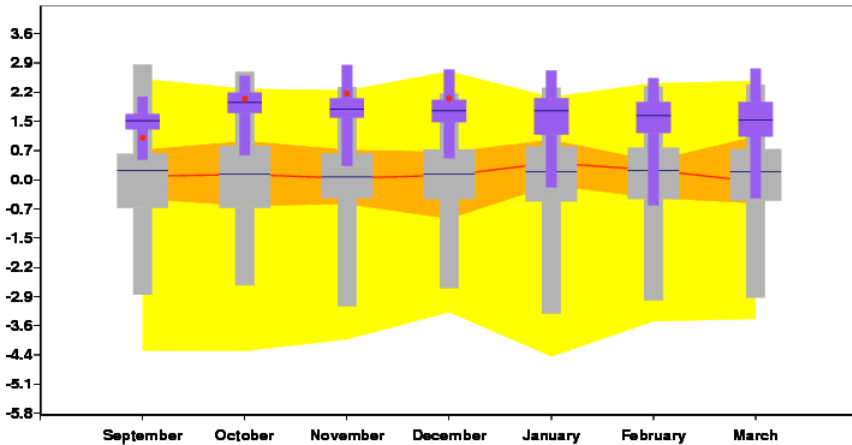
Anomaly correlation: Equatorial Southern Oscillation



Equatorial Southern Oscillation

Forecast initial date: 2011 901

Ensemble size: Forecast=51 Model climate=450 Analysis climate=30



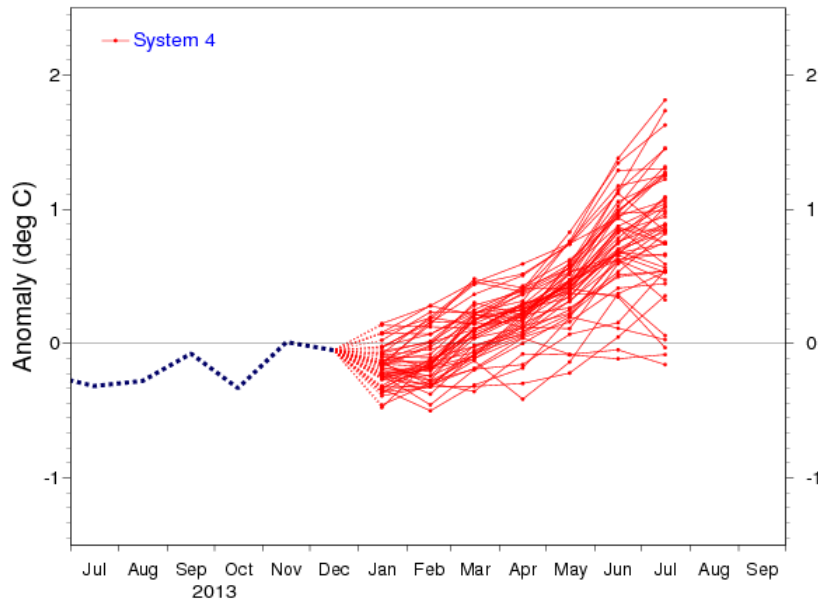
EUROSIP multi-model system:

4 Coupled Systems: ECMWF, Météo France, Met Office, NCEP

- **Ensemble generation for the 4 systems is different**
- **Development of multi-model products is ongoing**
- **EUROSIP products are available to WMO users**

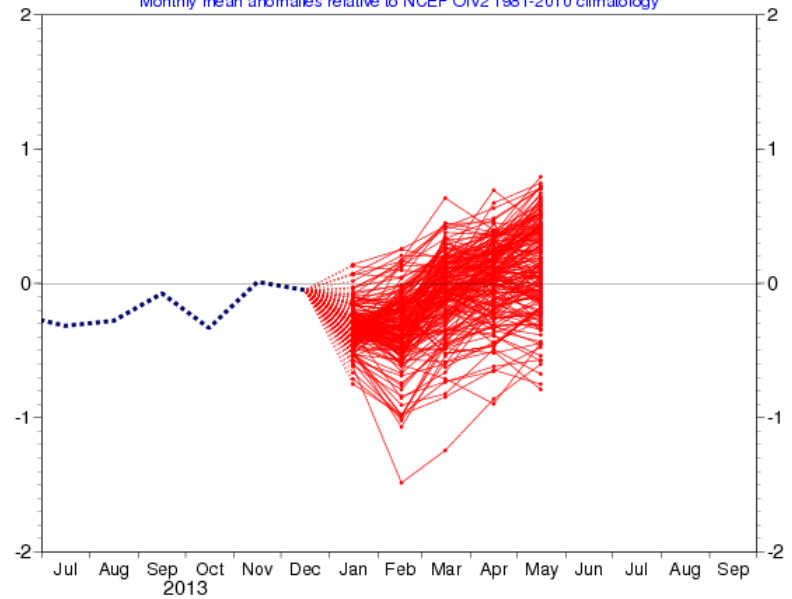
EUROSIP

NINO3.4 SST anomaly plume
ECMWF forecast from 1 Jan 2014
Monthly mean anomalies relative to NCEP OIv2 1981-2010 climatology



ECMWF

NINO3.4 SST anomaly plume
EUROSIP multi-model forecast from 1 Jan 2014
ECMWF, Met Office, Météo-France, NCEP
Monthly mean anomalies relative to NCEP OIv2 1981-2010 climatology

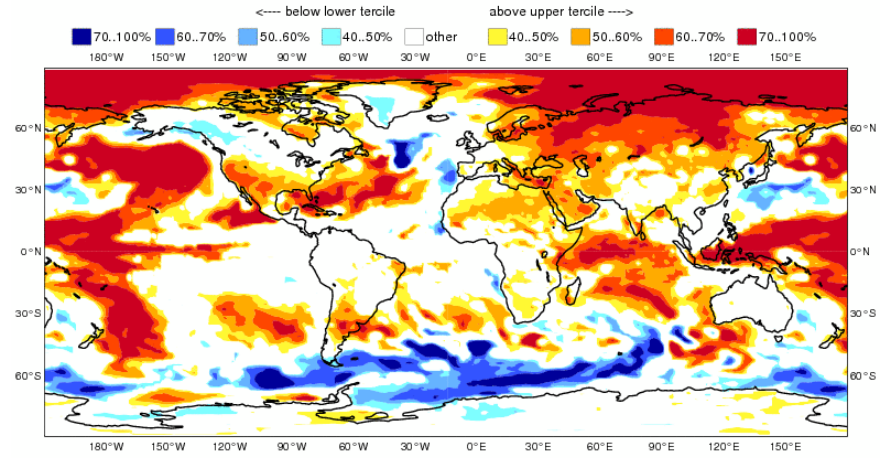


ECMWF

Eurosip is issued on the 15th of the month

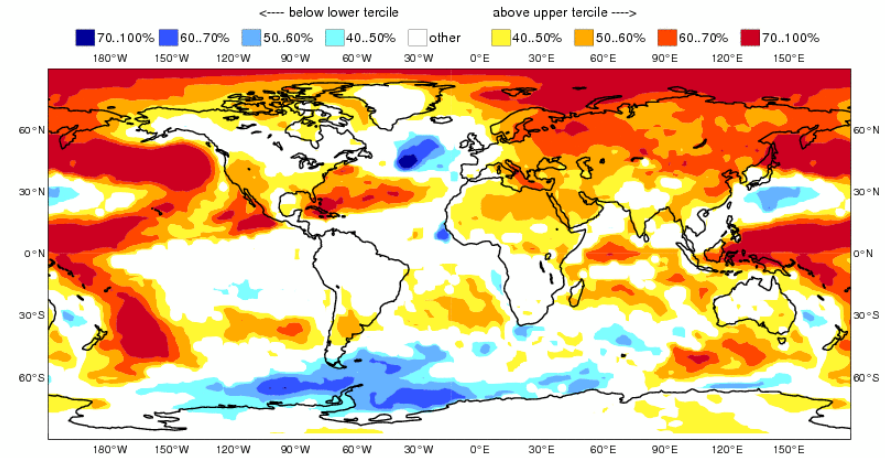
ECMWF Seasonal Forecast
Prob(most likely category of 2m temperature)
Forecast start reference is 01/01/14
Ensemble size = 51, climate size = 450

System 4
MAM 2014



EUROSIP multi-model seasonal forecast
Prob(most likely category of 2m temperature)
Forecast start reference is 01/01/14
Unweighted mean

ECMWF/Met Office/Meteo-France/NCEP
MAM 2014



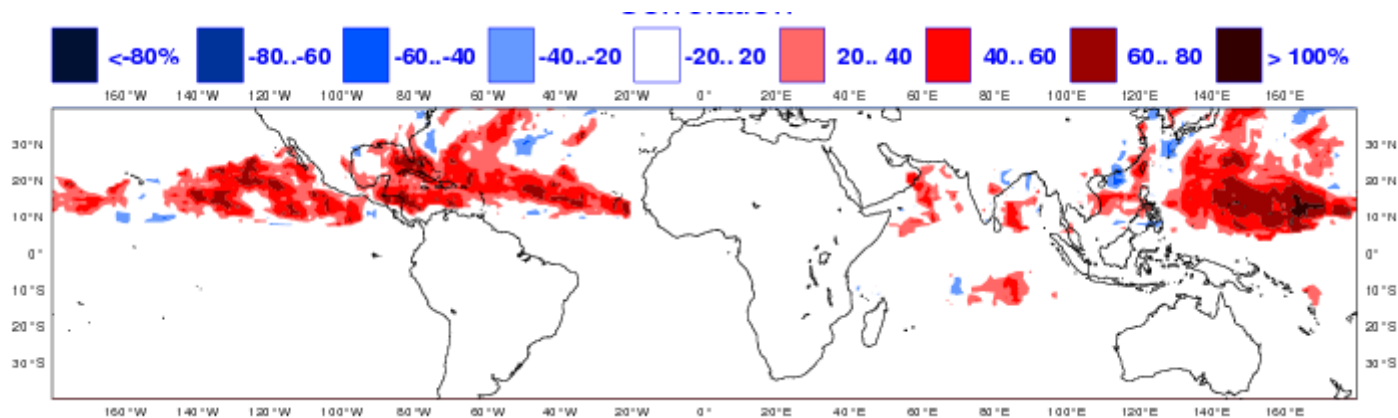
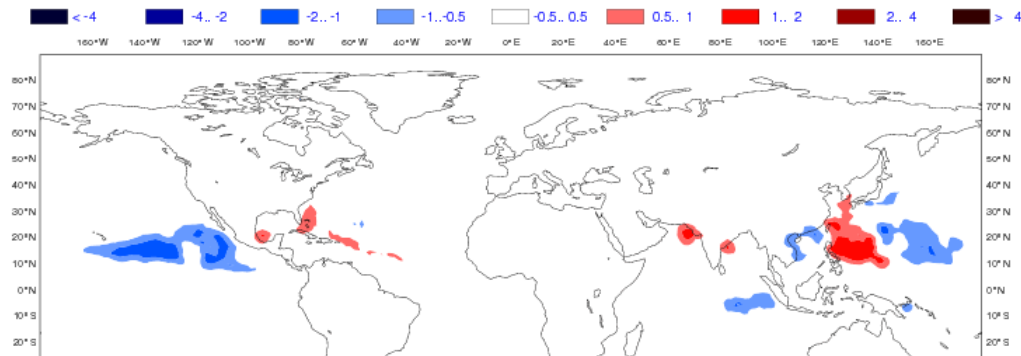
Summary (2)

- 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](http://www.ecmwf.int/publications)

Cyclone track density new product from S4 and its verification

ECMWF Seasonal Forecast
Tropical Storm Density Anomaly
Forecast start reference is 01/05/2011
Ensemble size = 51, climate size = 300

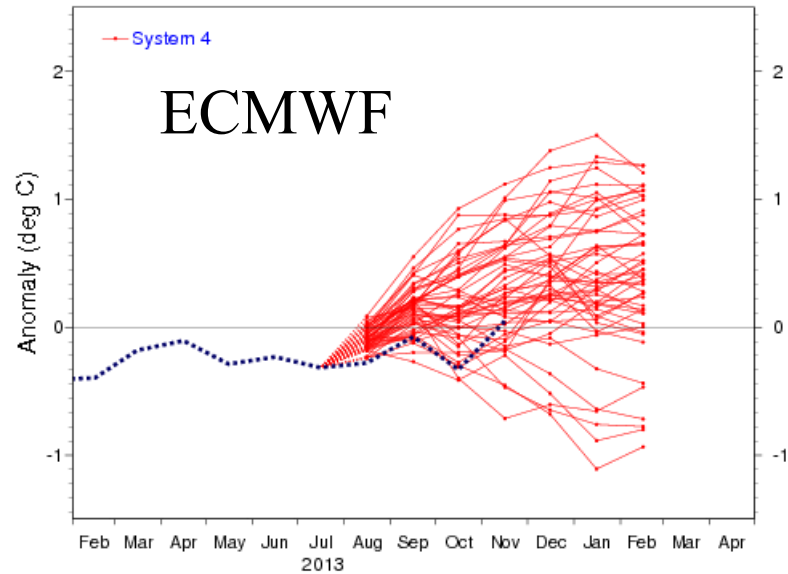
System 4
JJASON 2011
Climate = 1990-2009



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

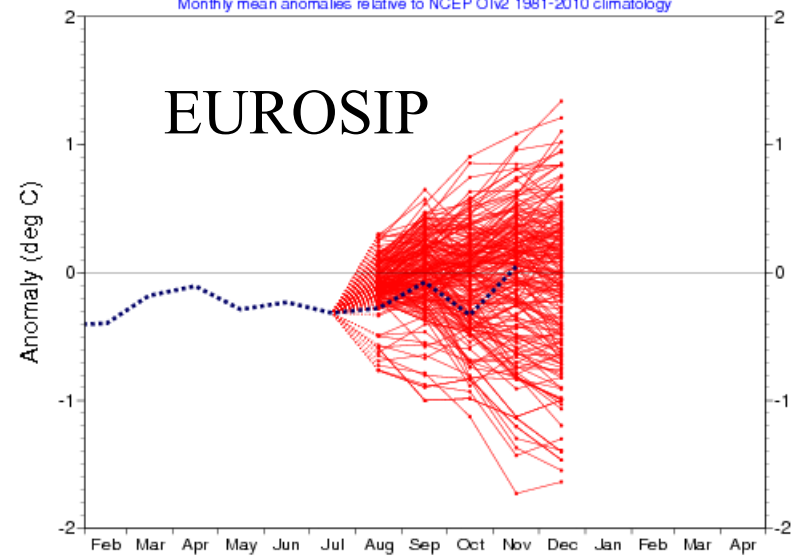
NINO3.4 SST anomaly plume
ECMWF forecast from 1 Aug 2013

Monthly mean anomalies relative to NCEP OIv2 1981-2010 climatology



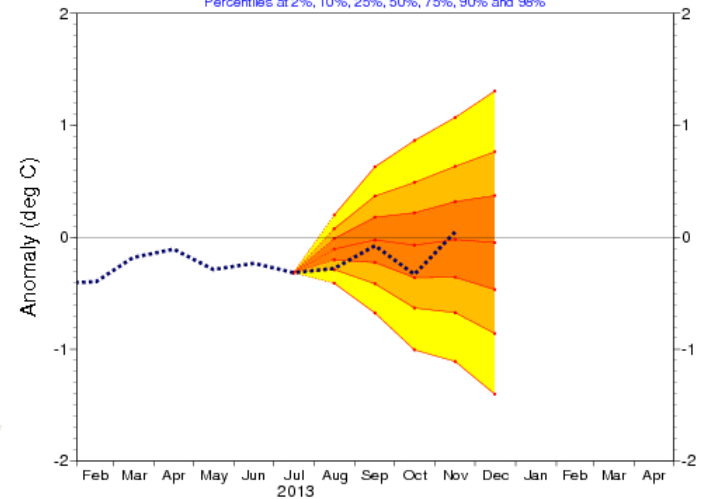
NINO3.4 SST anomaly plume
EUROSIP multi-model forecast from 1 Aug 2013

ECMWF, Met Office, Météo-France, NCEP
Monthly mean anomalies relative to NCEP OIv2 1981-2010 climatology



NINO3.4 SST calibrated pdf
EUROSIP multi-model forecast from 1 Aug 2013

ECMWF, Met Office, Météo-France, NCEP
Percentiles at 2%, 10%, 25%, 50%, 75%, 90% and 98%



2m temperature anomalies SON

2013

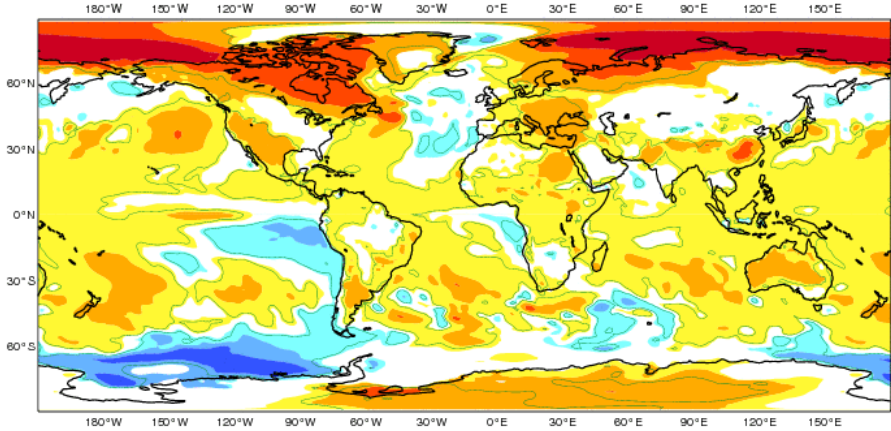
ECMWF

y

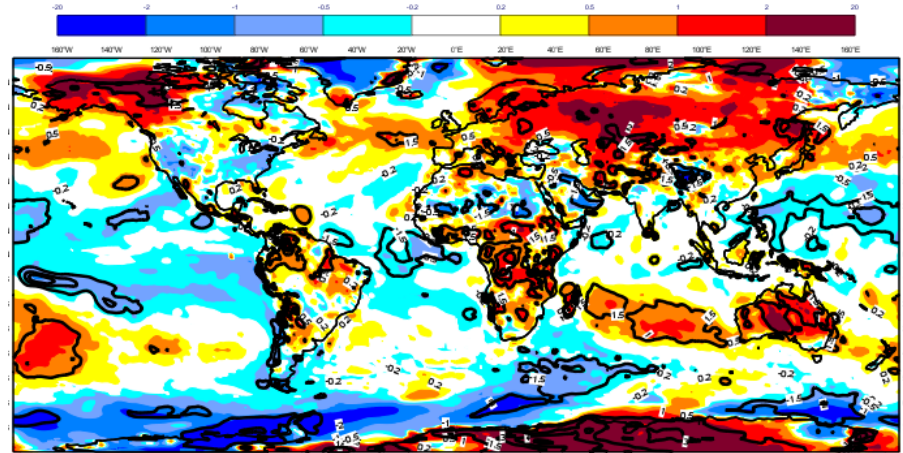
System 4
SON 2013

Shaded areas significant at 10% level
Solid contour at 1% level

■ <-2.0°C ■ -2.0..-1.0 ■ -1.0..-0.5 ■ -0.5..0 ■ No Signal ■ 0..0.5 ■ 0.5..1.0 ■ 1.0..2.0 ■ > 2.0°C



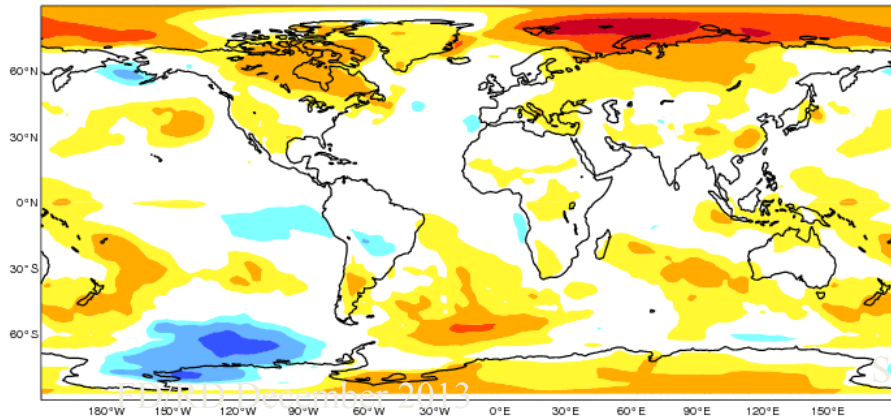
ANALYSIS



EUROSIP

ECMWF/Met Office/Meteo-France/NCEP
SON 2013

■ <-2.0°C ■ -2.0..-1.0 ■ -1.0..-0.5 ■ -0.5..-0.2 ■ -0.2..0.2 ■ 0.2..0.5 ■ 0.5..1.0 ■ 1.0..2.0 ■ > 2.0°C



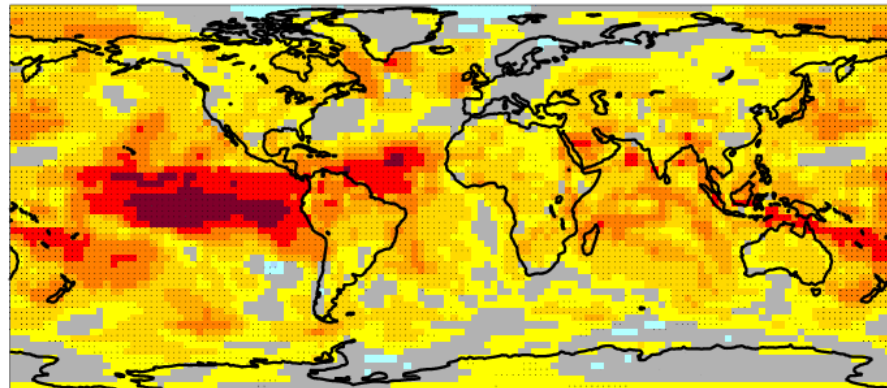
ECMWF skill

with 15 ensemble members

forecast period 1997-2016 with start in August average over months 2 to 4

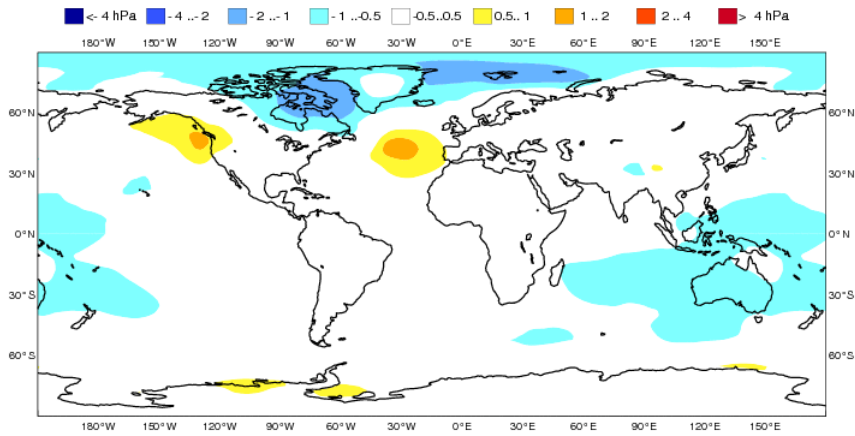
Black dots for values significantly different from zero with 95% confidence (1000 samples)

-1 -0.9 -0.8 -0.7 -0.6 -0.5 -0.4 -0.3 -0.2 0.2 0.4 0.6 0.7 0.8 0.9 1.13932e+09



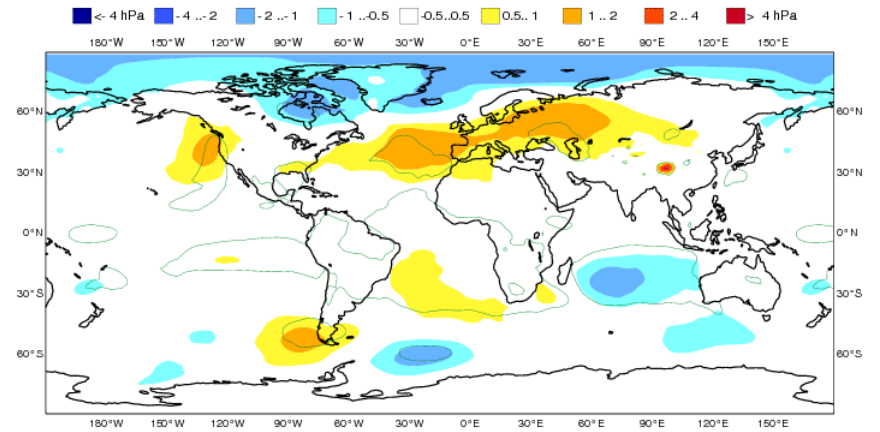
EUROSIP multi-model seasonal forecast
 Mean MSLP anomaly
 Forecast start reference is 01/11/13
 Variance-standardized mean

ECMWF/Met Office/Meteo-France/NCEP
 DJF 2013/14



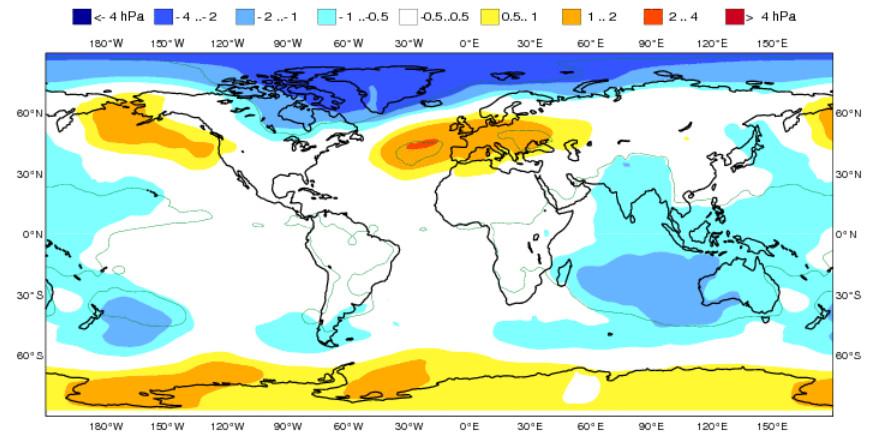
ECMWF Seasonal Forecast
 Mean MSLP anomaly
 Forecast start reference is 01/11/13
 Ensemble size = 51, climate size = 450

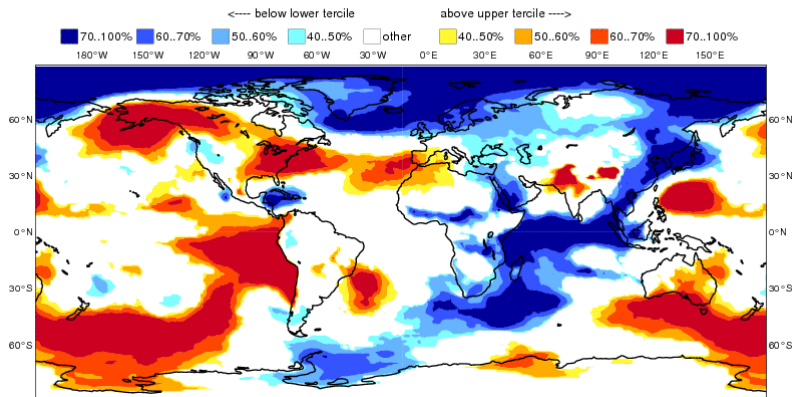
System 4
 DJF 2013/14
 Solid contour at 1% significance level



EUROSIP: Met Office contribution
 Mean MSLP anomaly
 Forecast start reference is 01/11/13
 Ensemble size = 40, climate size = 168

System 9
 DJF 2013/14
 Solid contour at 1% significance level



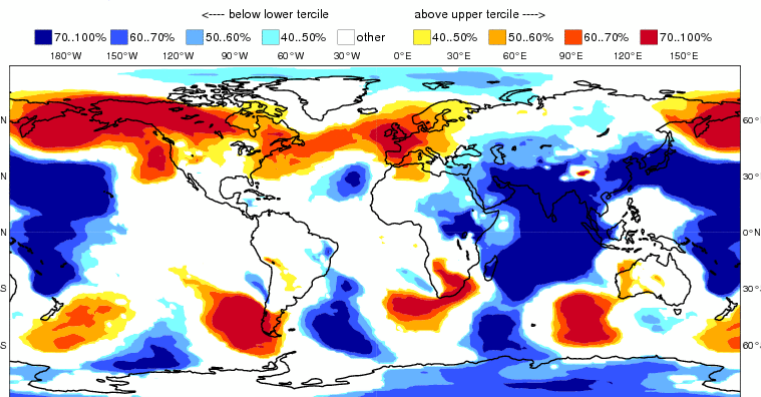


Prob(most likely category of MSLP)

Forecast start reference is 01/11/13

Ensemble size = 51, climate size = 450

DEC 2013

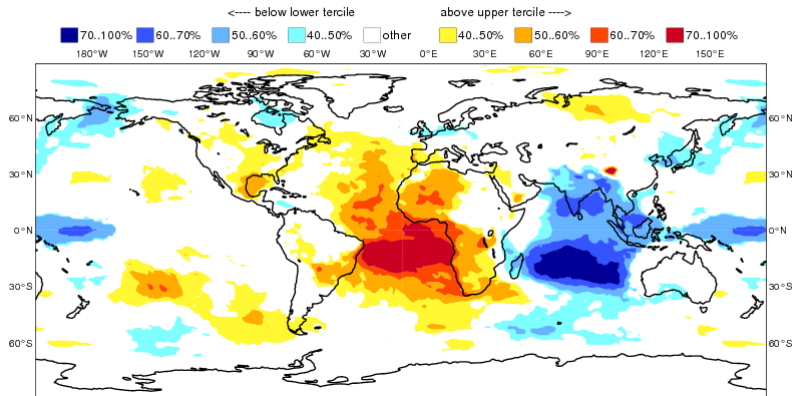


Prob(most likely category of MSLP)

Forecast start reference is 01/12/13

Ensemble size = 51, climate size = 450

JAN 2014

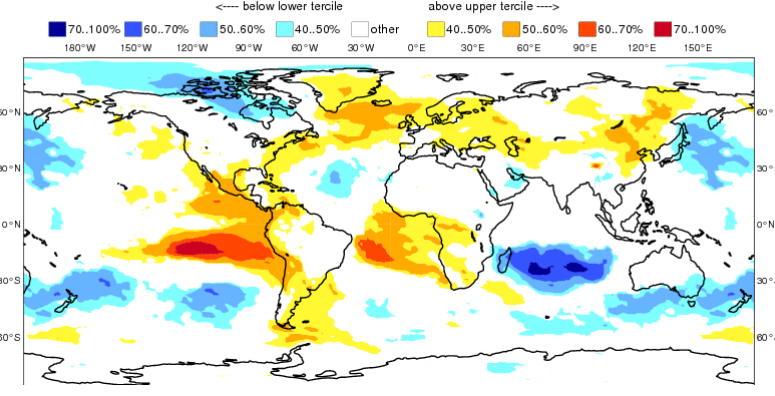


Prob(most likely category of MSLP)

Forecast start reference is 01/11/13

Ensemble size = 51, climate size = 450

JAN 2014

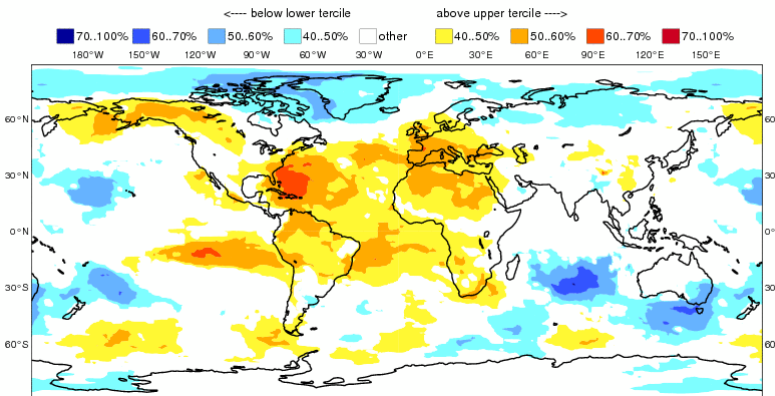
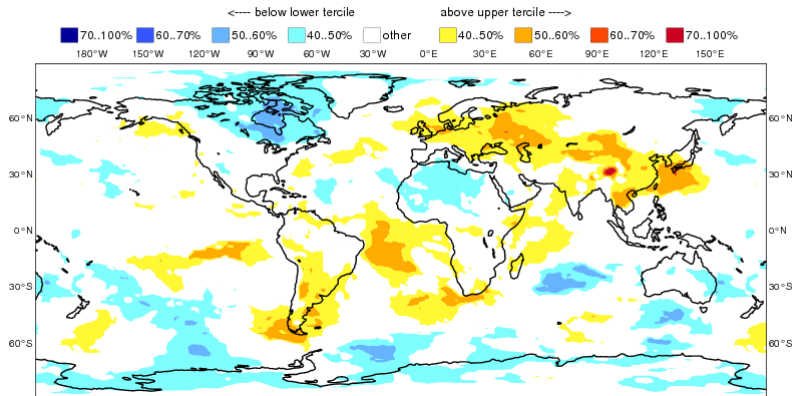


Prob(most likely category of MSLP)

Forecast start reference is 01/12/13

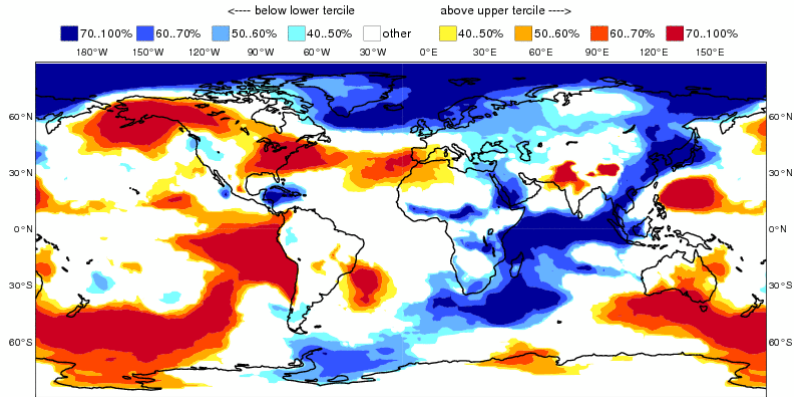
Ensemble size = 51, climate size = 450

FEB 2014



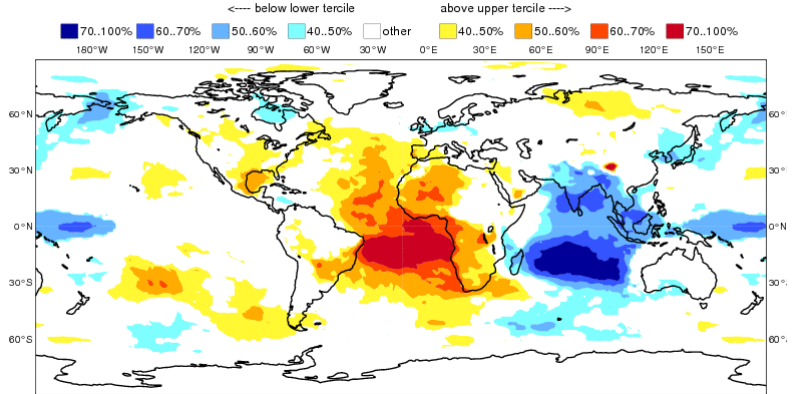
ECMWF Seasonal Forecast
Prob(most likely category of MSLP)
Forecast start reference is 01/11/13
Ensemble size = 51, climate size = 450

System 4
NOV 2013



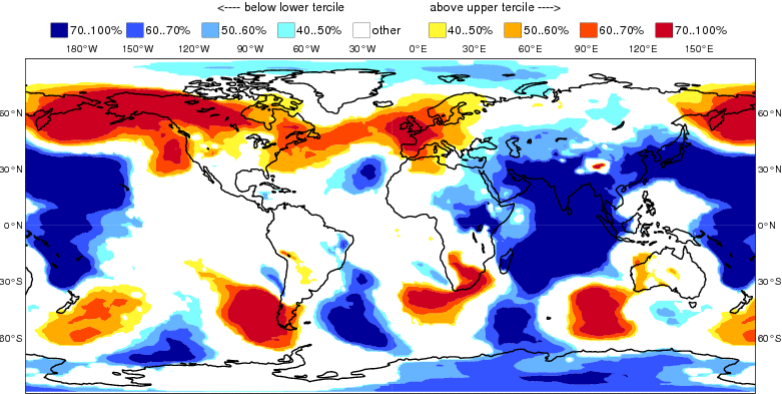
Prob(most likely category of MSLP)
Forecast start reference is 01/11/13
Ensemble size = 51, climate size = 450

DEC 2013



ECMWF Seasonal Forecast
Prob(most likely category of MSLP)
Forecast start reference is 01/12/13
Ensemble size = 51, climate size = 450

System 4
DEC 2013

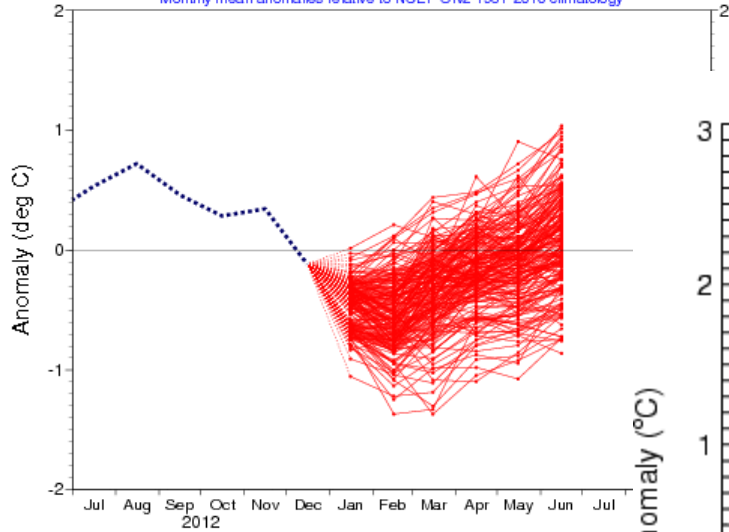


3.4 outlook

NINO3.4 SST anomaly plume
EUROSIP multi-model forecast from 1 Jan 2013

ECMWF, Met Office, Météo-France, NCEP

Monthly mean anomalies relative to NCEP OIv2 1981-2010 climatology



ENSO Predictions from Feb 2011 to Nov 2012

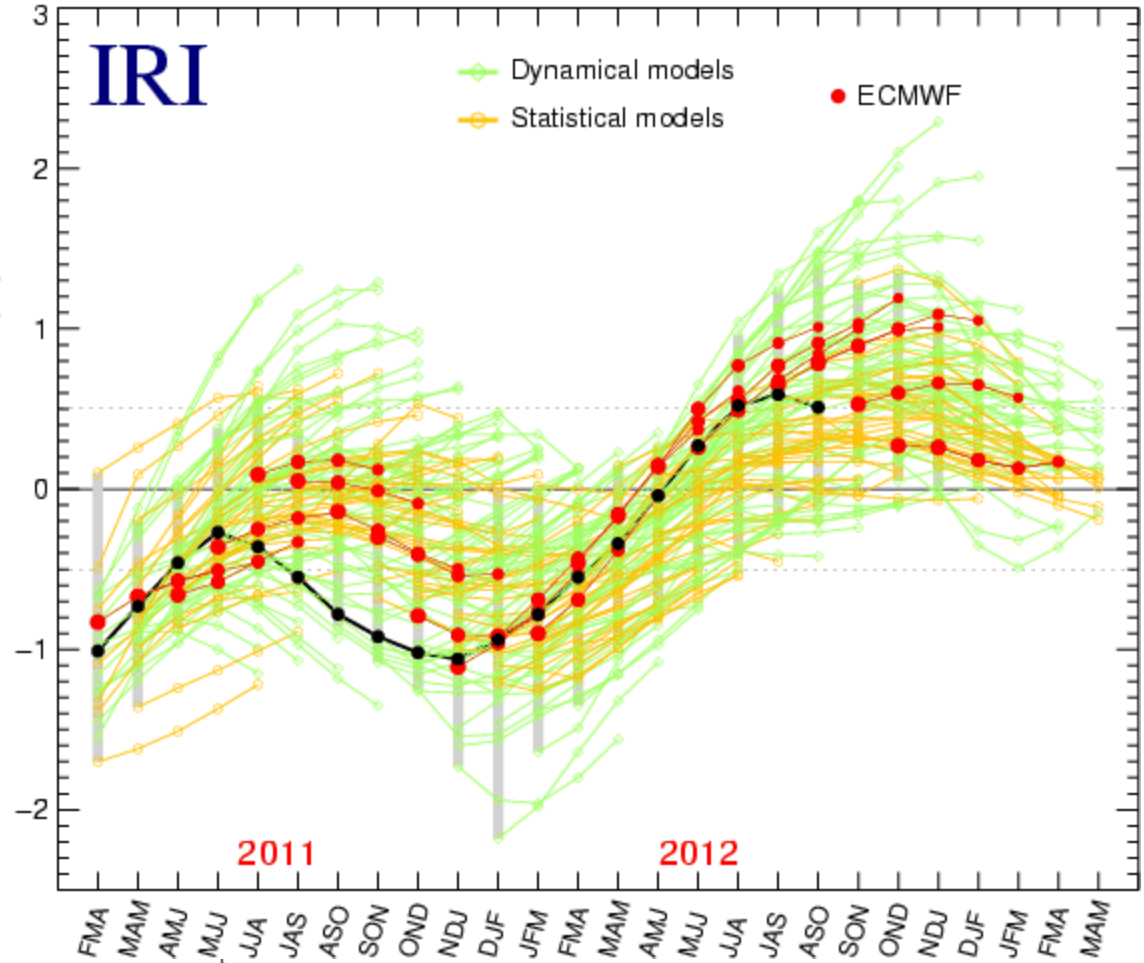
IRI

◇ Dynamical models

○ Statistical models

● ECMWF

Nino3.4 SST Anomaly (°C)

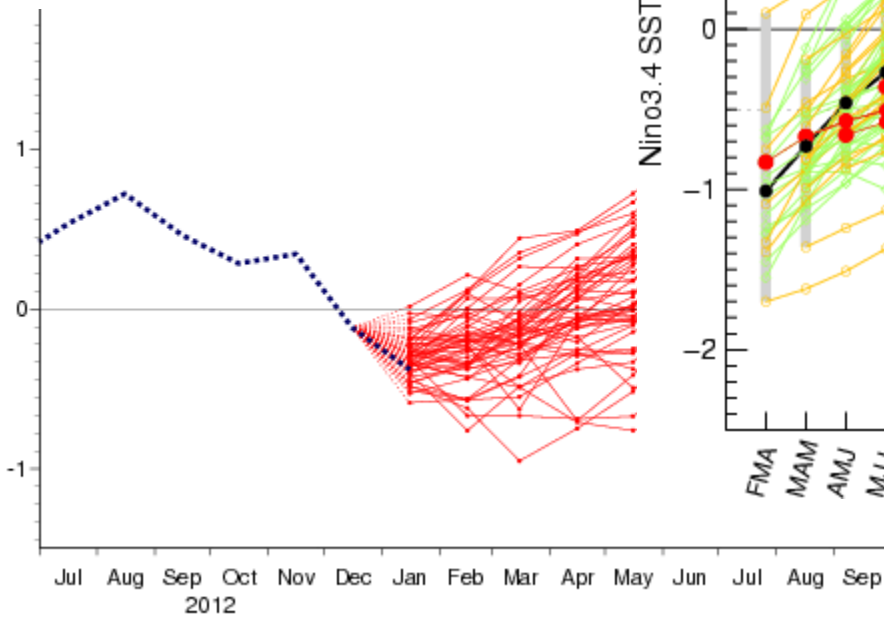


2011

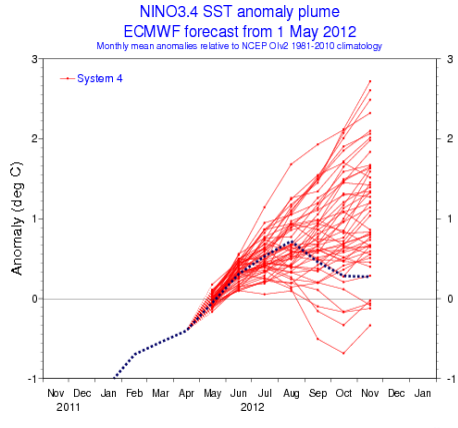
2012

FMA MAM AMJ MJJ JJA JAS ASO SON OND NDJ DJF JFM FMA MAM AMJ MJJ JJA JAS ASO SON OND NDJ DJF JFM FMA MAM

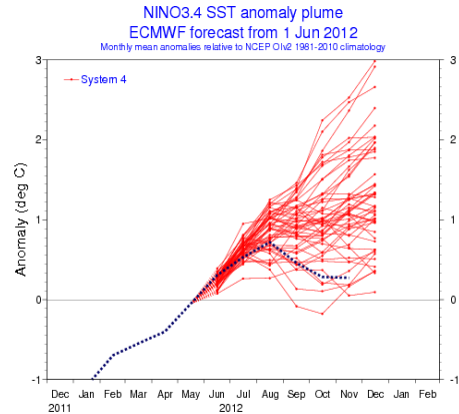
Anomaly (deg C)



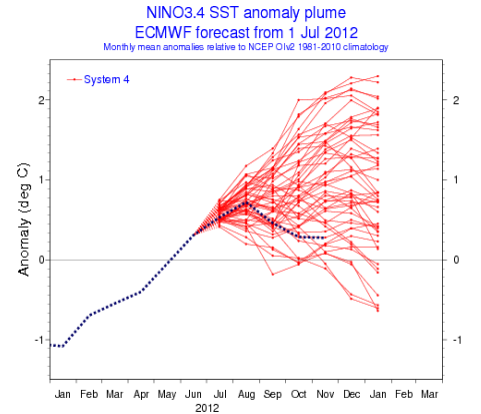
NINO 3.4 past predictions



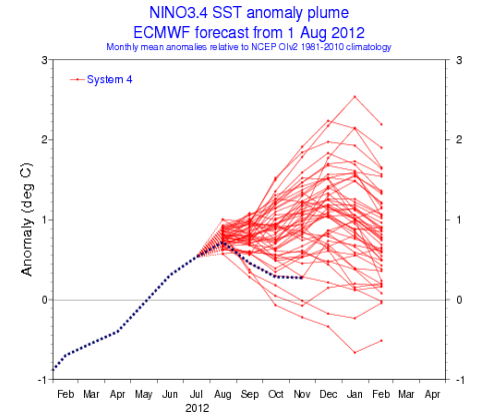
ECMWF



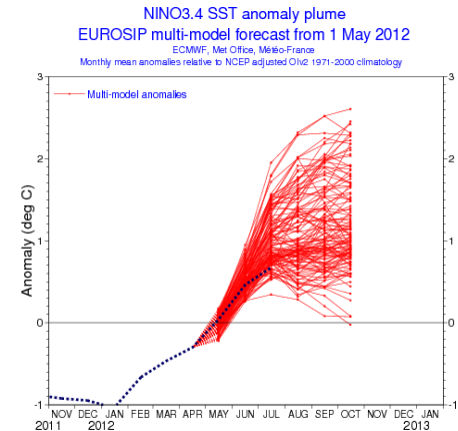
ECMWF



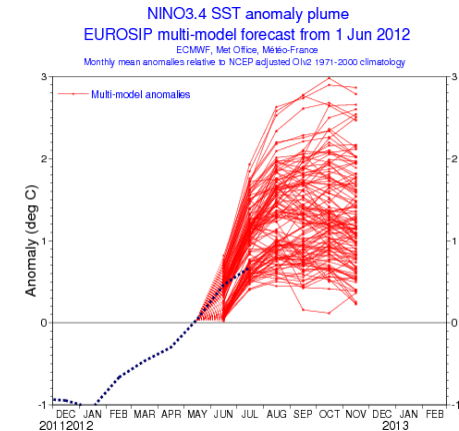
ECMWF



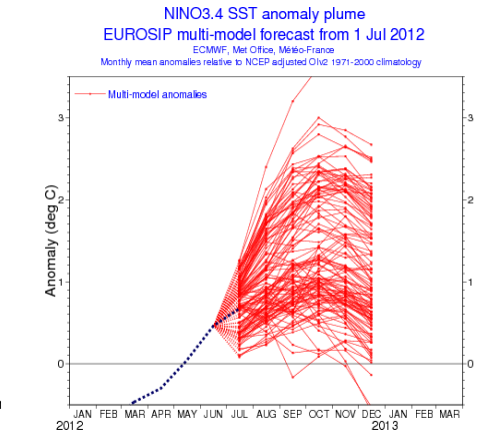
ECMWF



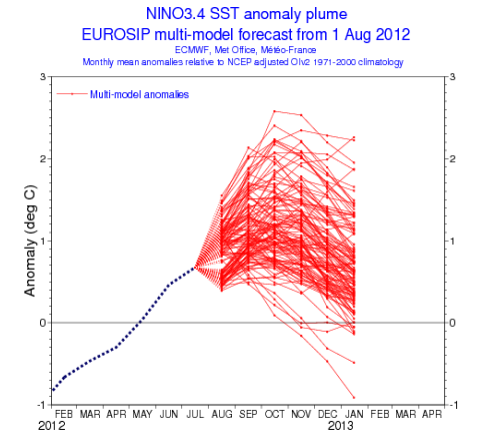
ECMWF



ECMWF



ECMWF



ECMWF

Forecast issue date: 15 May 2012

Forecast issue date: 15 Jun 2012

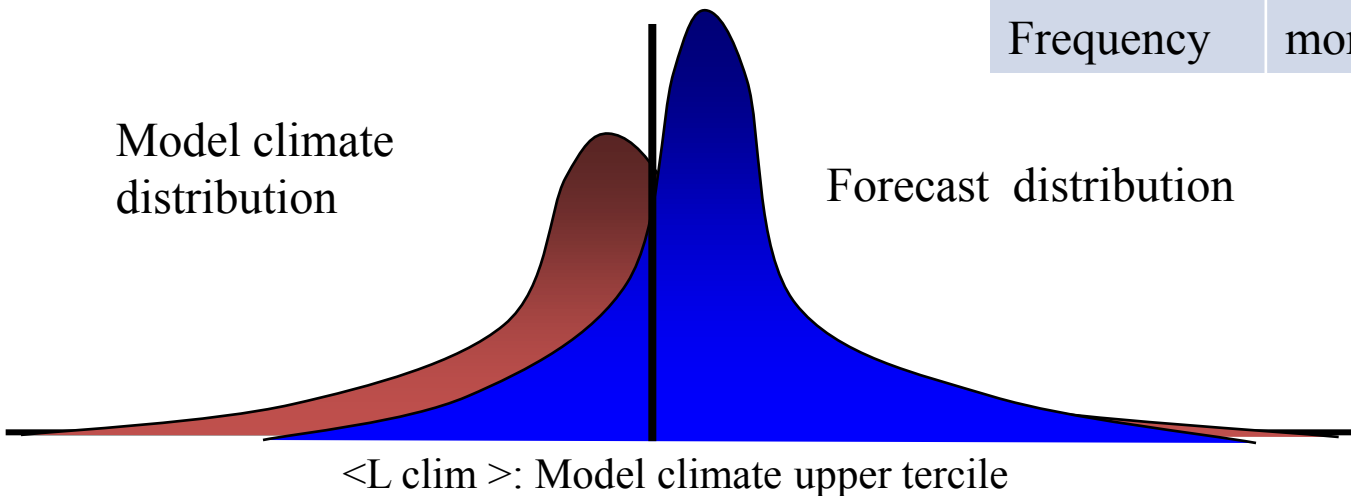
Forecast issue date: 15 Jul 2012

Forecast issue date: 15 Aug 2012

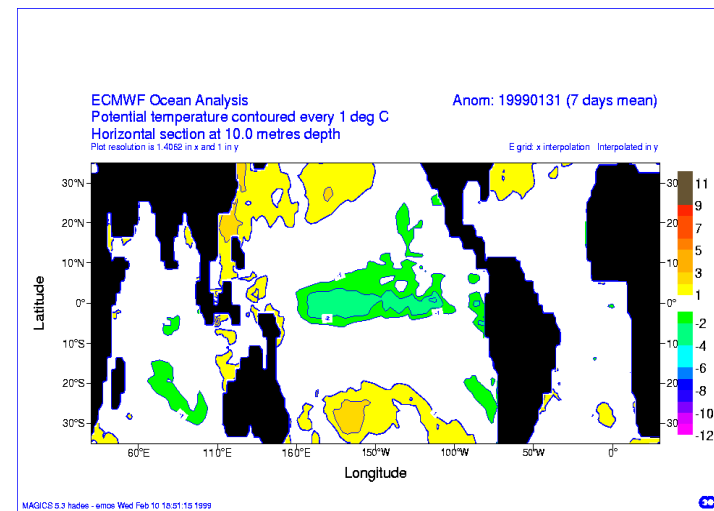
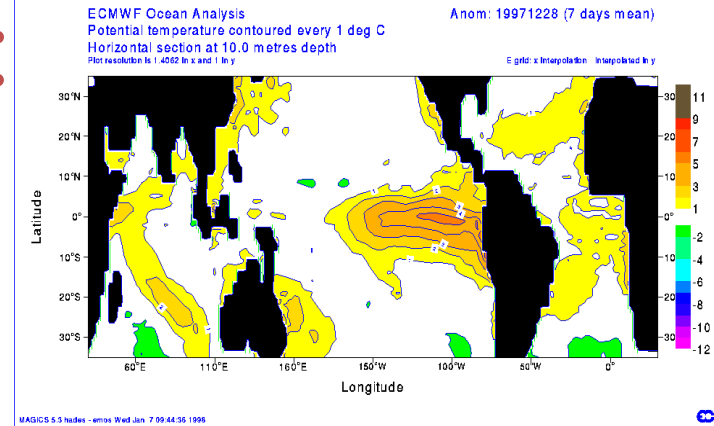
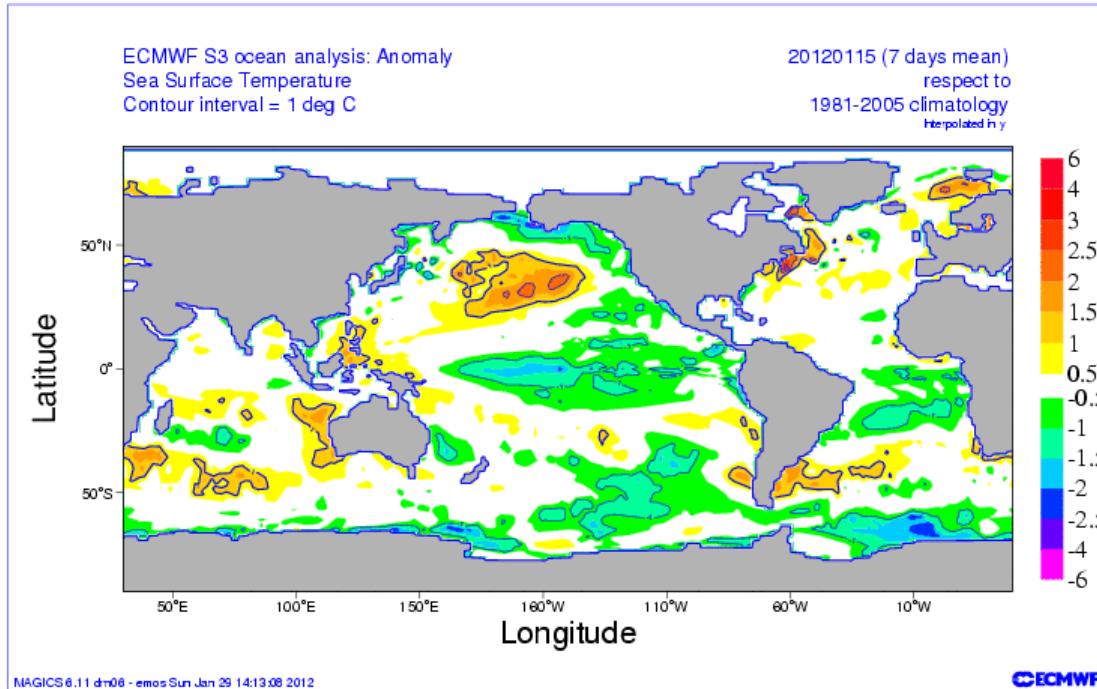
Extended range predictions

- 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 |



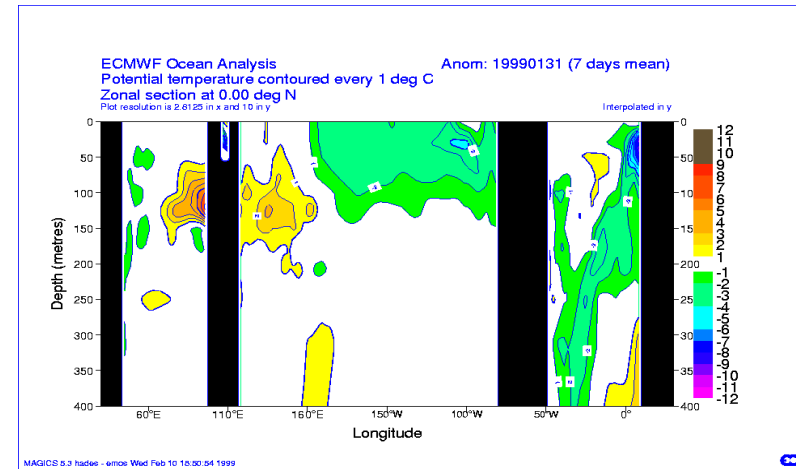
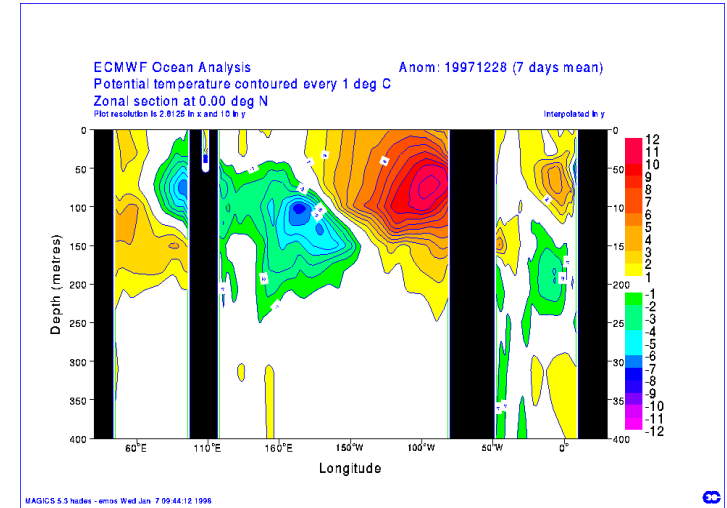
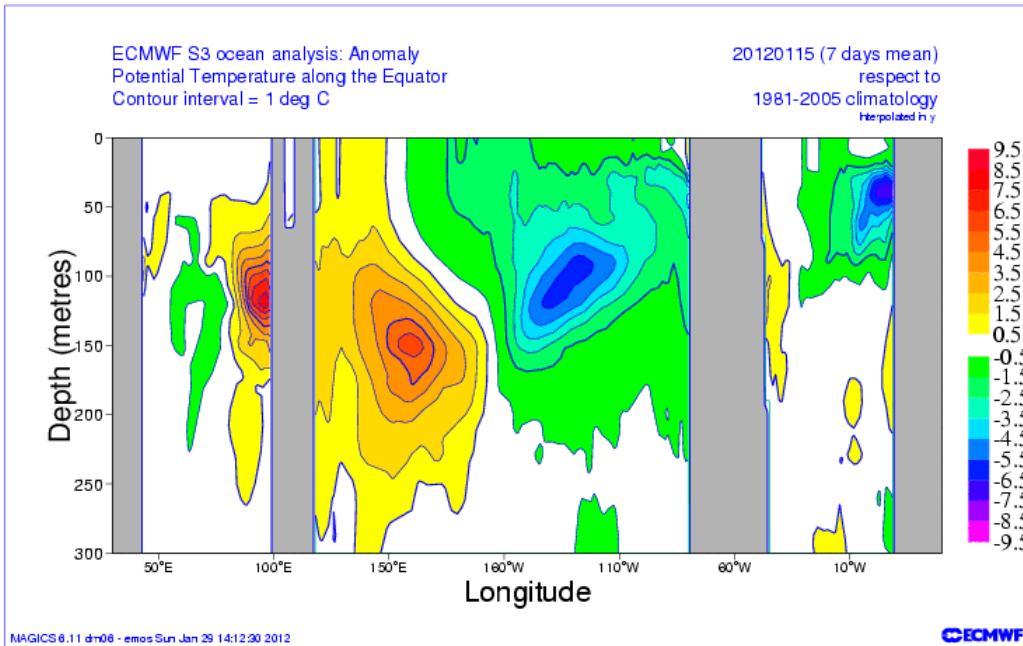
Ocean analysis:



Daily weekly and monthly products are available on the web

11/02/2014

Ocean analysis:

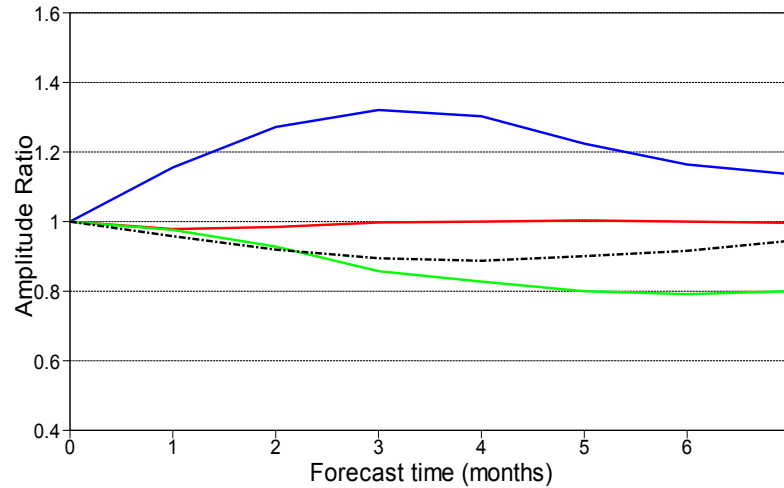


Chaotic nature of the atmosphere:

- 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.

Calibration of ENSO SST indices

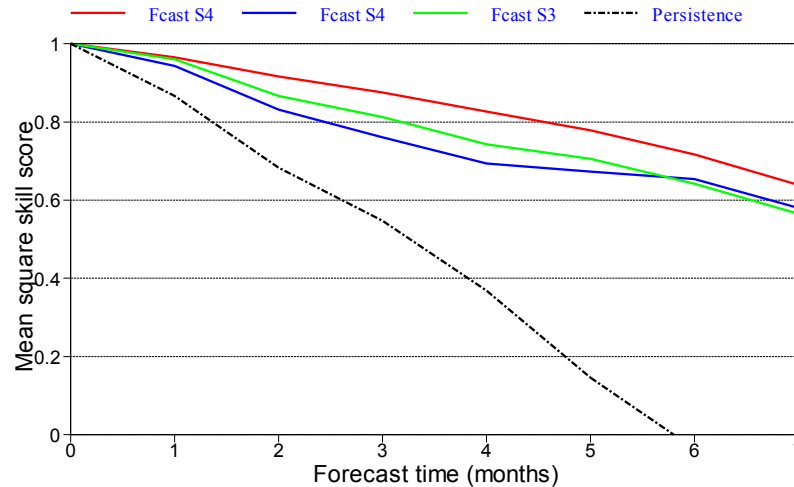
NINO3 SST anomaly amplitude ratio



S4 non calib.
S4 calibrated
S3

NINO3 SST mean square skill scores

150 start dates from 19910201 to 20081101, various corrections
Ensemble sizes are 15 (0001), 11 (0001) and 11 (0001)

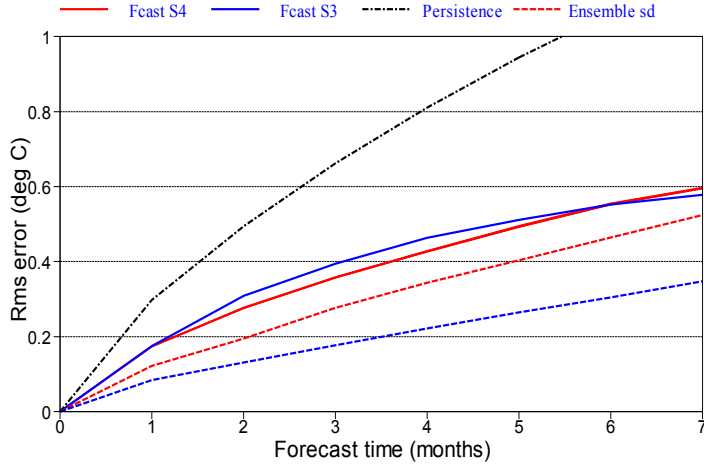


SST scores: Nino 3.4 and Eq.

Atlantic

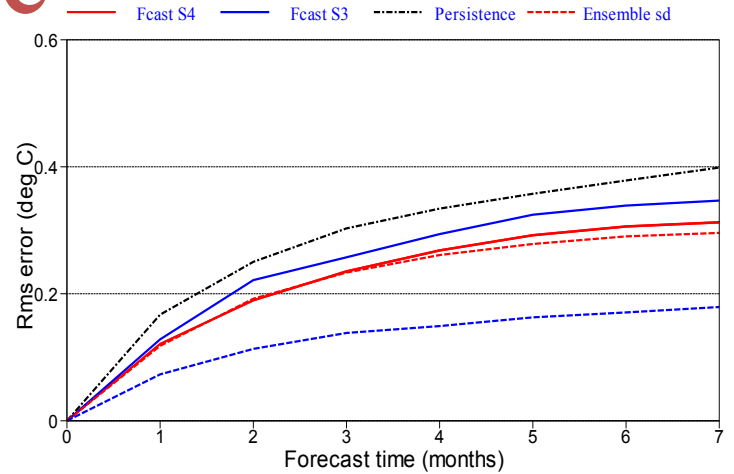
NINO3.4 SST rms errors

360 start dates from 19810101 to 20101201, various corrections
 Ensemble sizes/corrections are 15/AS (0001) and 11/BC (0001)
 95% confidence interval for 0001, for given set of start dates



EQATL SST rms errors

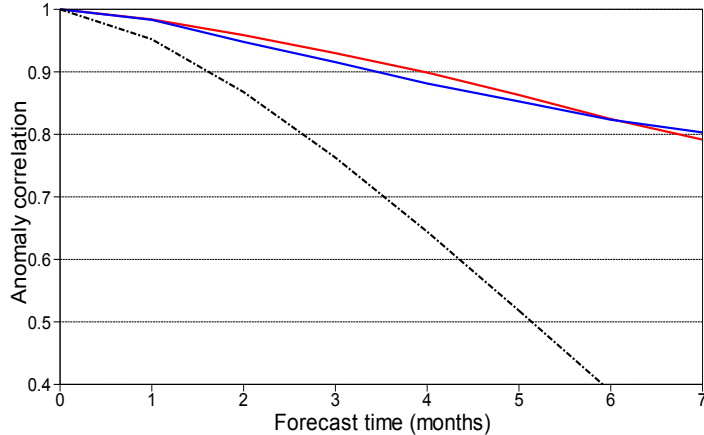
360 start dates from 19810101 to 20101201, various corrections
 Ensemble sizes/corrections are 15/AS (0001) and 11/BC (0001)
 95% confidence interval for 0001, for given set of start dates



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

NINO3.4 SST anomaly correlation

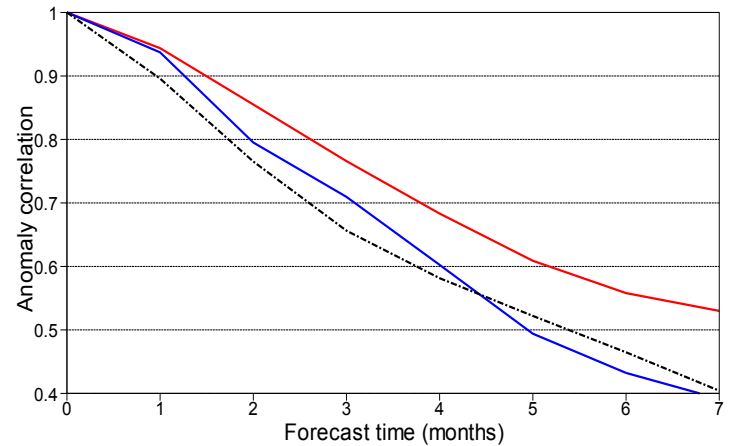
wrt NCEP adjusted OI2 1971-2000 climatology



S4 ACC
 S3 ACC
 Pers.
 ACC

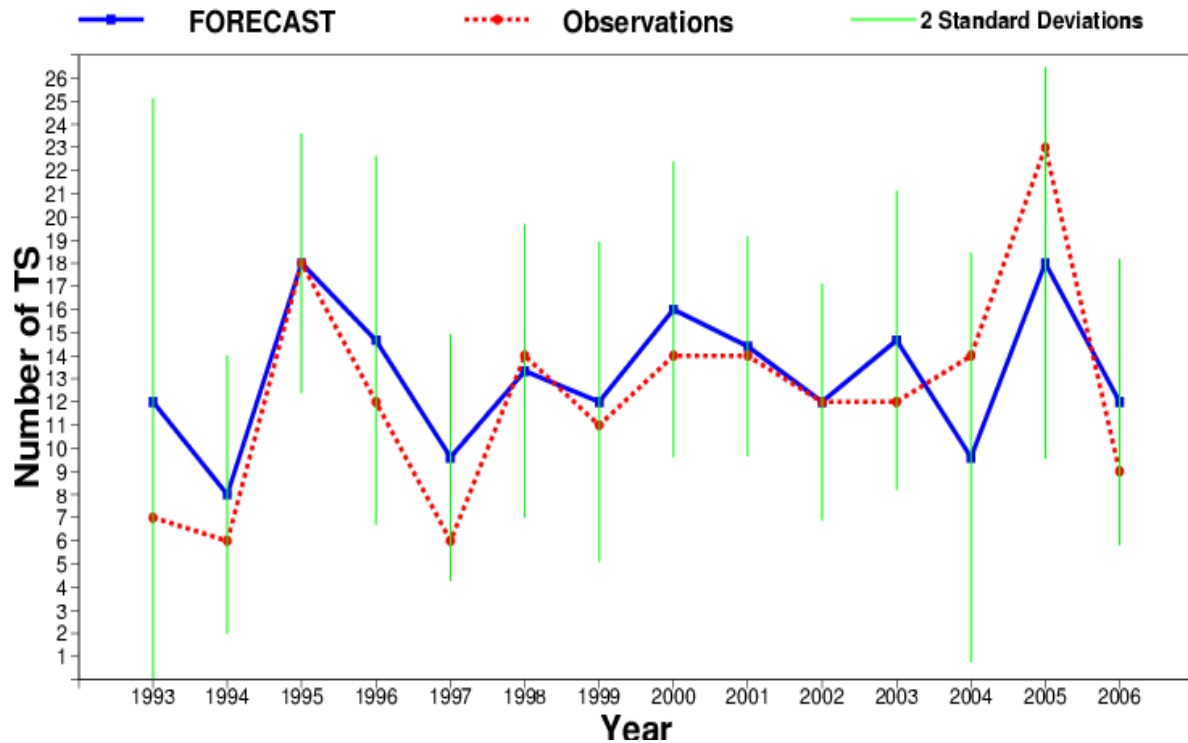
EQATL SST anomaly correlation

wrt NCEP adjusted OI2 1971-2000 climatology



EUROsip seasonal forecasts of tropical storms

Forecasts starting on 1st June



Bias in S4 re-forecasts: SST (DJF)

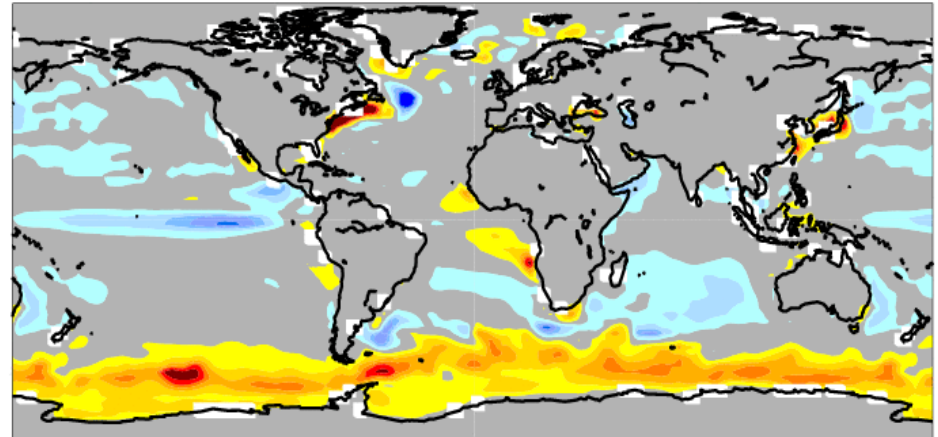
Start: 1 Nov.

1981/2010

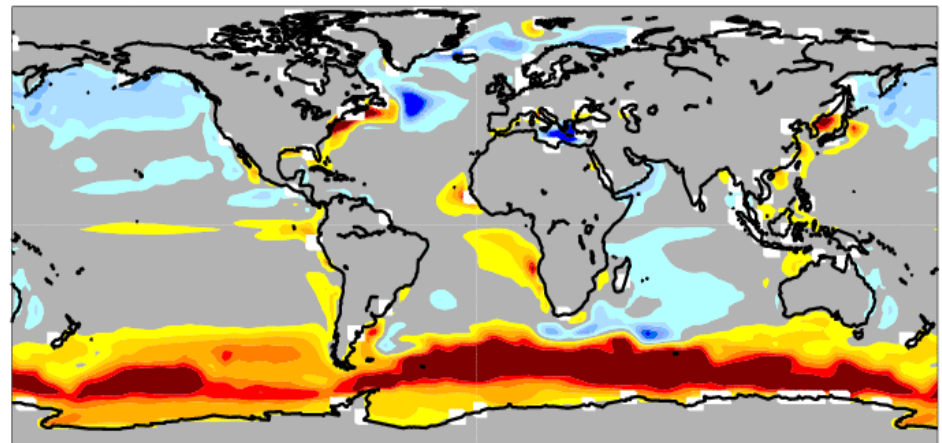
Verify: Dec-Feb

System 4

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



System 3



Bias in S4 re-forecasts: rainfall (JJA)

Start: 1 May

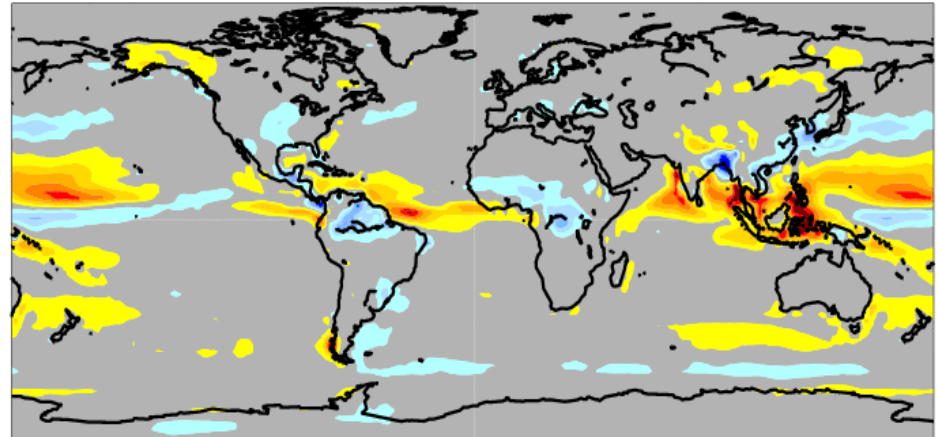
1981/2010

Verify: Jun-Aug

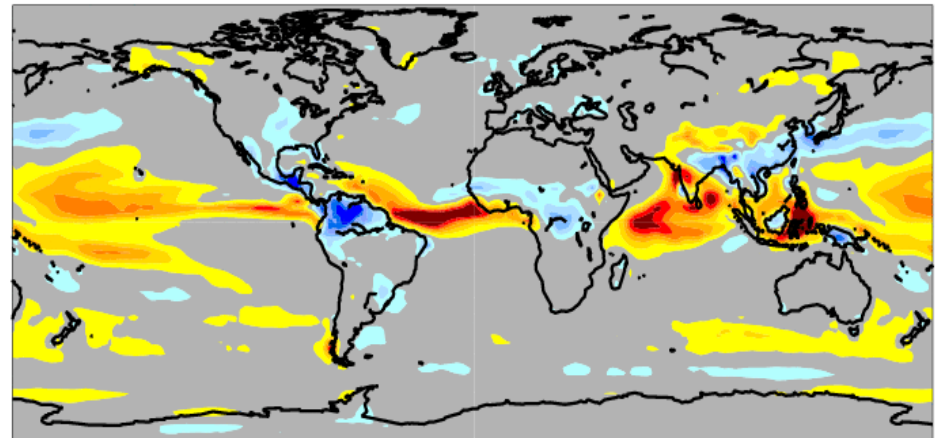
System 4

Precipitation

Hindcast period 1981-2008 with start in May average over months 2 to 4



System 3



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

Start: 1 May

1981/2010

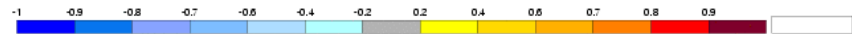
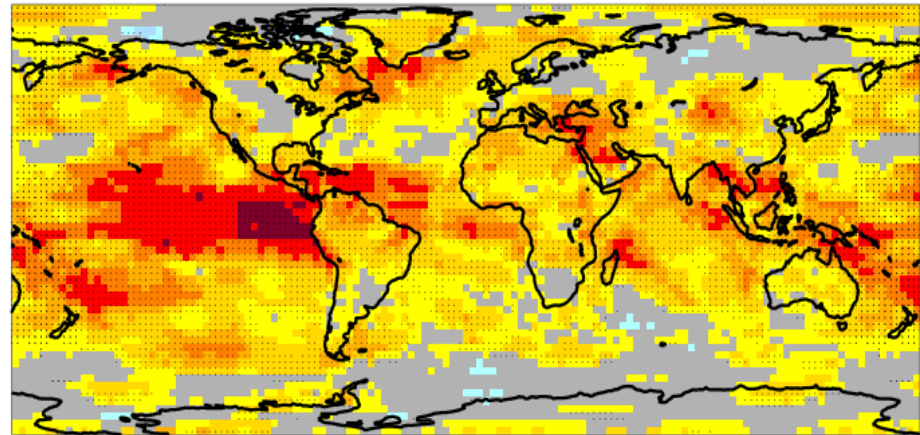
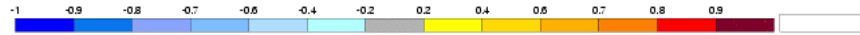
Verify: Jun-Aug

System 4

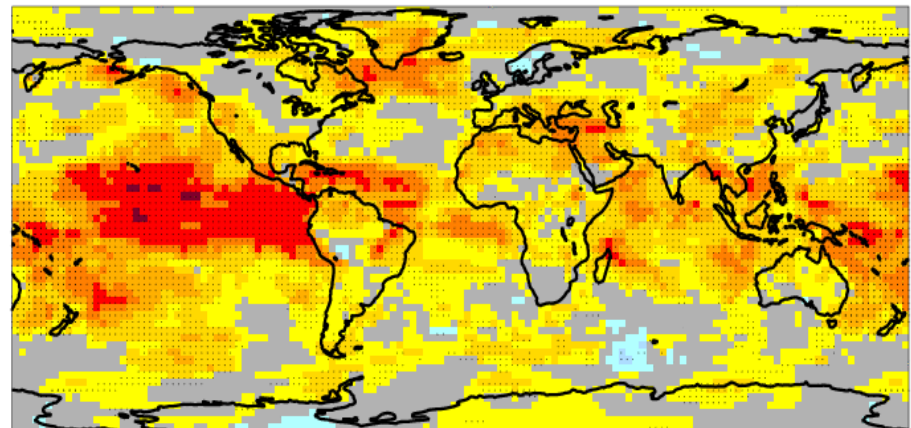
Near-surface air temperature

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

Black dots for values significantly different from zero with 95% confidence (1000 samples)



System 3



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.