Motivation and ingredients for a seasonal forecasting system

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Many thanks to Franco Molteni, Laura Ferranti, Tim Stockdale, Magdalena Balmaseda and many others at ECMWF

Outline:

- **Motivation for seasonal forecasting**
- **Basis for seasonal forecasting: it's a coupled business!**
- **Empirical Modelling**
- **Coupled Dynamical Modelling**
- **Getting dynamical models ready at the starting block**
- **Operational Seasonal forecasting (in Europe)**

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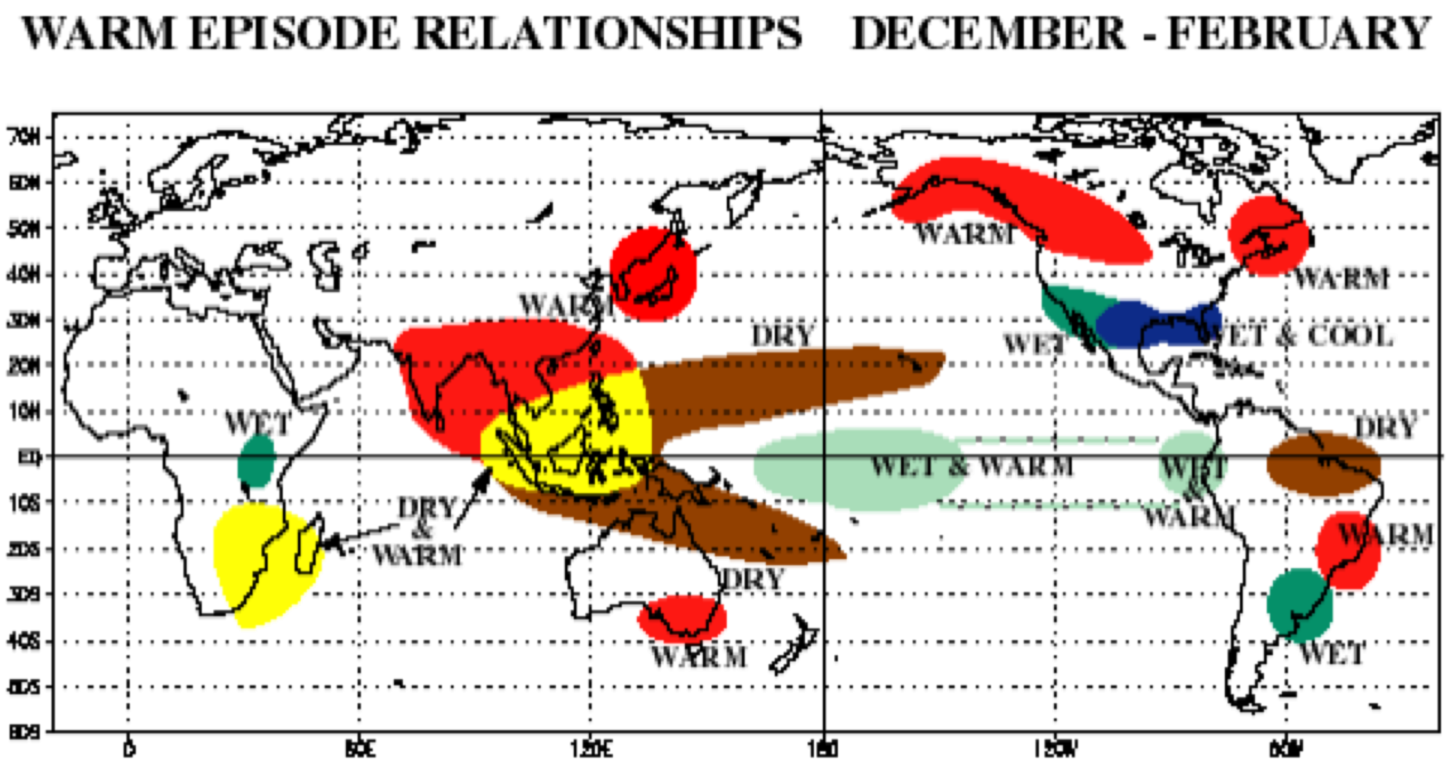
El Niño Major Impacts

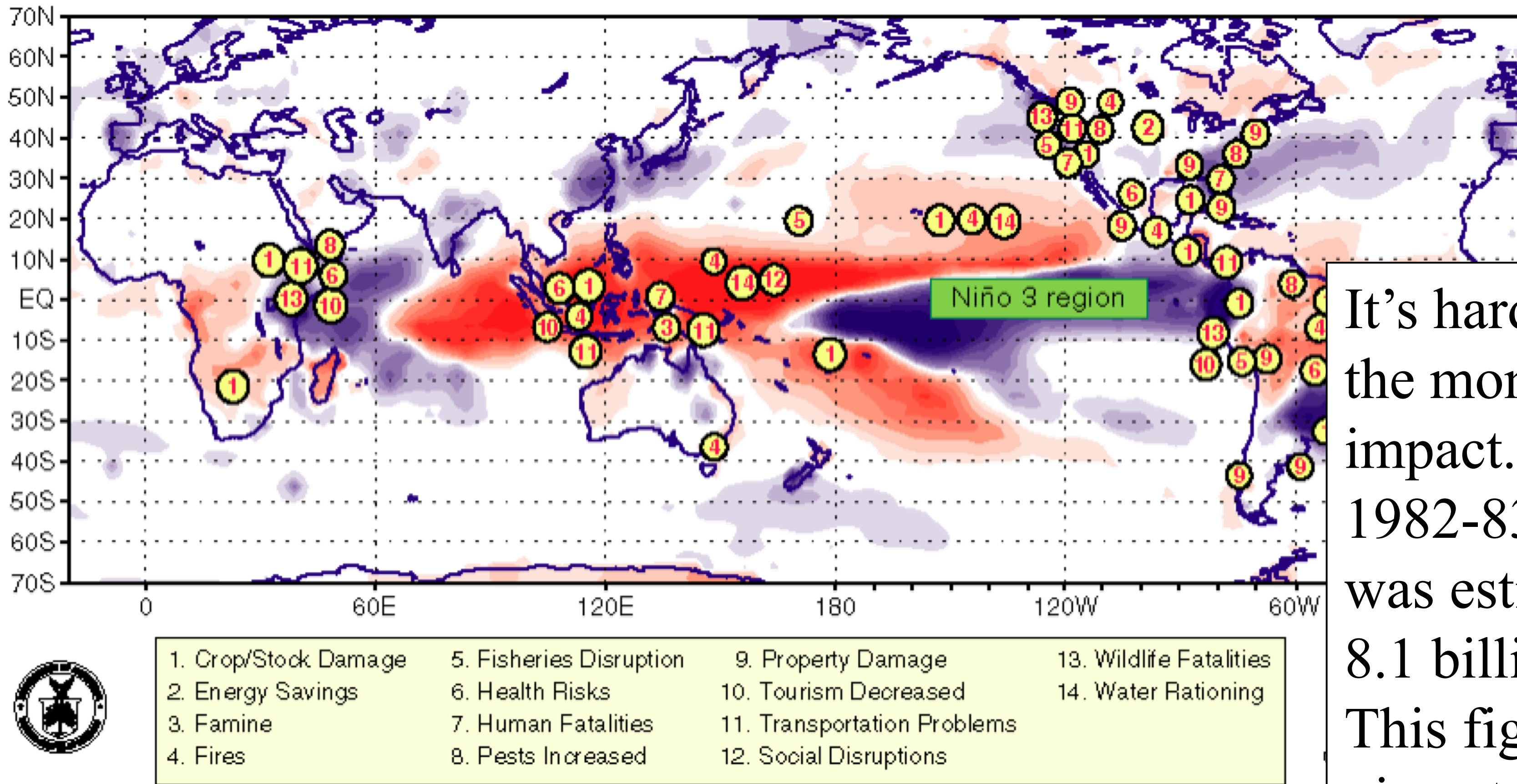
El Niño teleconnections



Courtesy Climate Prediction Center, NCEP, NOAA.

I am here referring to El Niño - the warm phase of the El Niño Southern Oscillation (ENSO) - even if teleconnections exist also for La Niña - the cold phase of ENSO – as we’ll see later.

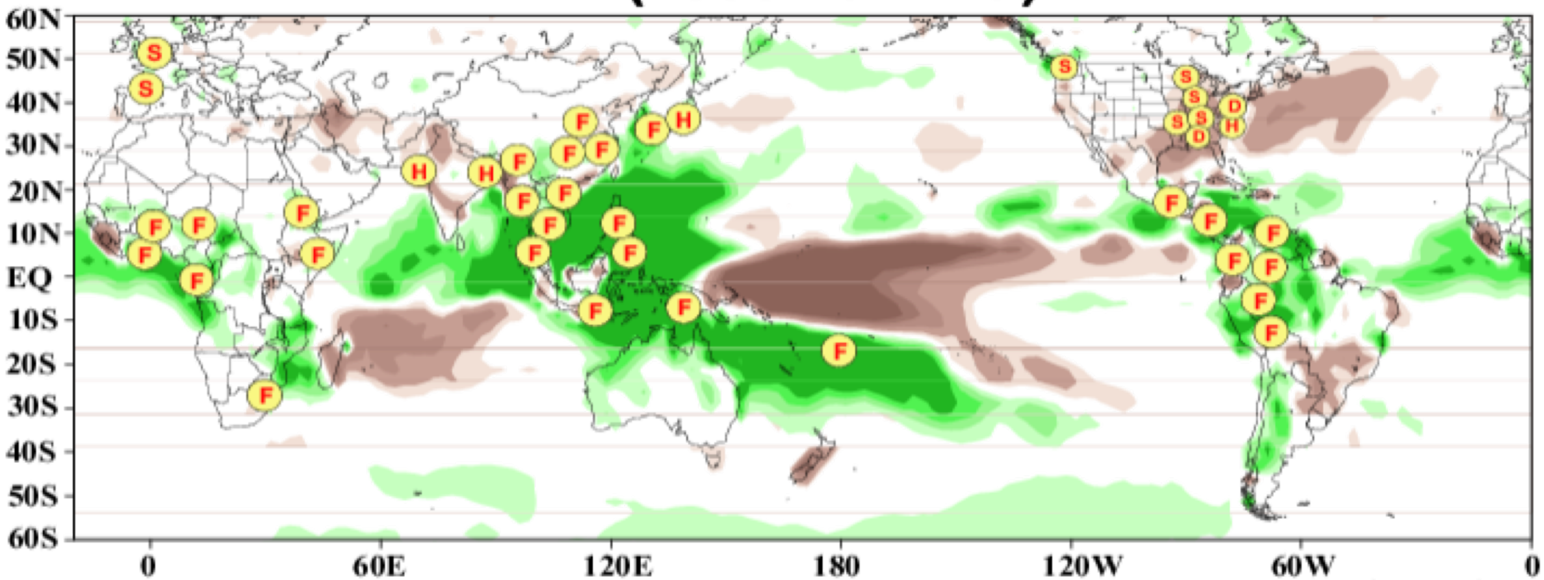
El Niño 1997-98 societal impacts



It's hard to estimate the monetary global impact. For the 1982-83 El Nino it was estimated to be 8.1 billion dollars. This figure is just given to give an idea of the scale of the event.

La Niña 1999 impacts

Major Weather-Related Natural Disasters (1999 La Nina)



S Storms, Hail, Tornadoes
F Floods, Landslides
H Hurricanes, Typhoons
D Drought

	Victims	Insured Losses
Flood	55,360	$1.3B
Storms	16,863	$17.0B
Droughts	404	-
Cold Waves	409	$1.3B

Climate Prediction Center

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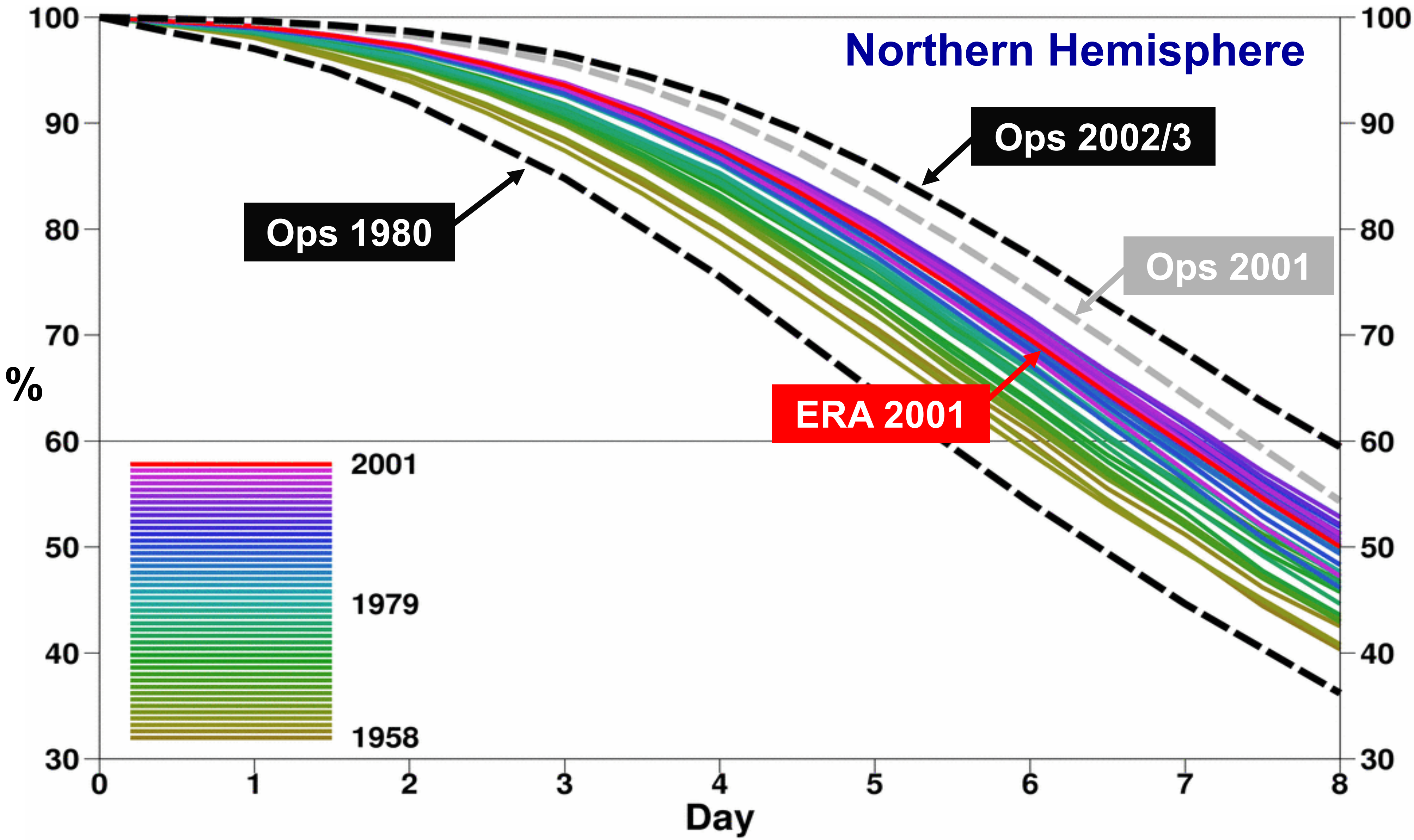
Anomaly correlations of 500hPa height forecasts

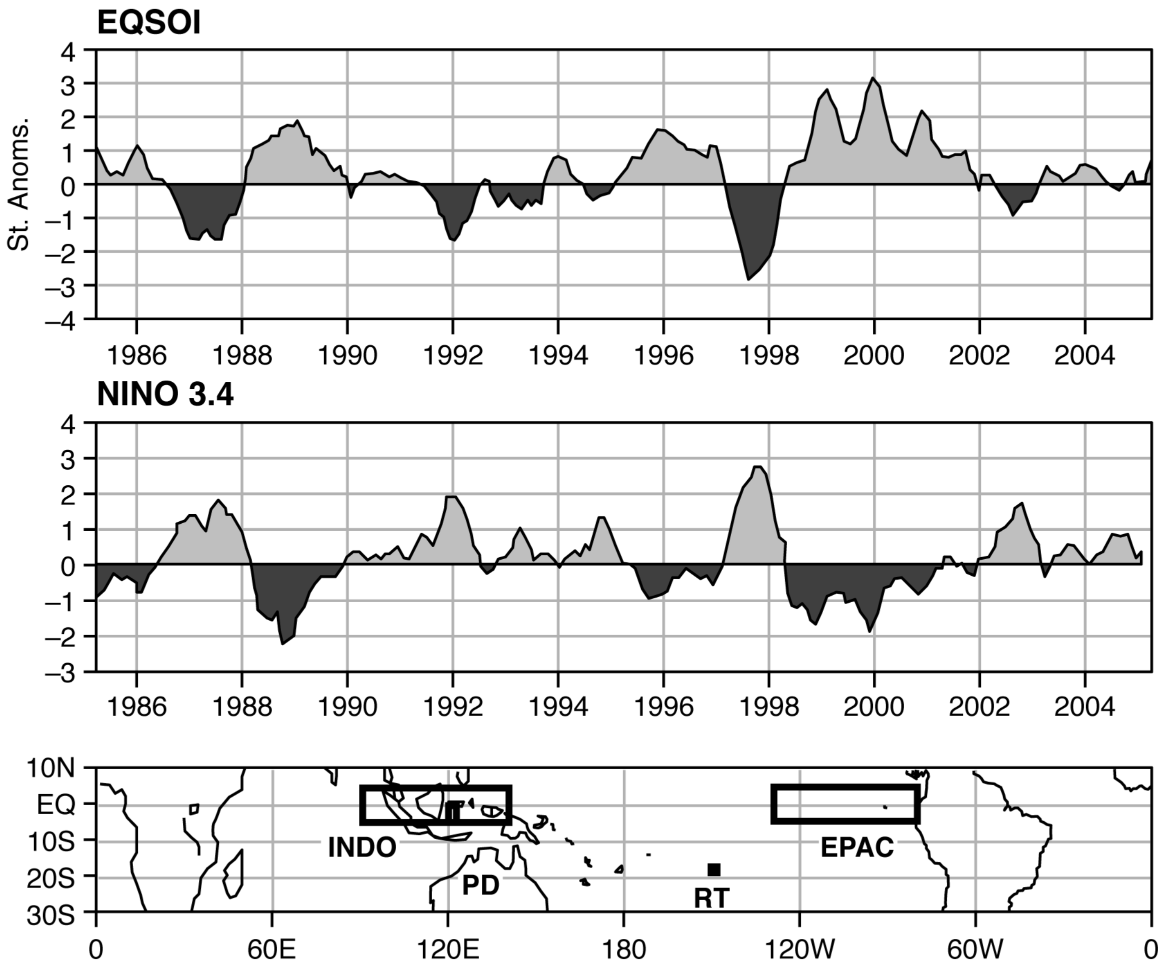


ECMWF

Predictability for seasonal forecasts

- The forecast horizon for weather forecasting is a few days
- Sometimes it is longer e.g. in blocking situations 5-10 days in the 30-60 day intraseasonal (or Madden Julian) oscillation
- But how can you predict 6 months (or maybe even further) ahead?
- … it all depends on what we are interested in … the longer the lead time the longer the averaging time and the larger the area average (e.g. in weather forecast one looks at temperature variation of several degrees at a location, in seasonal the variation may be of a few degrees over a region).

The ENSO evolution

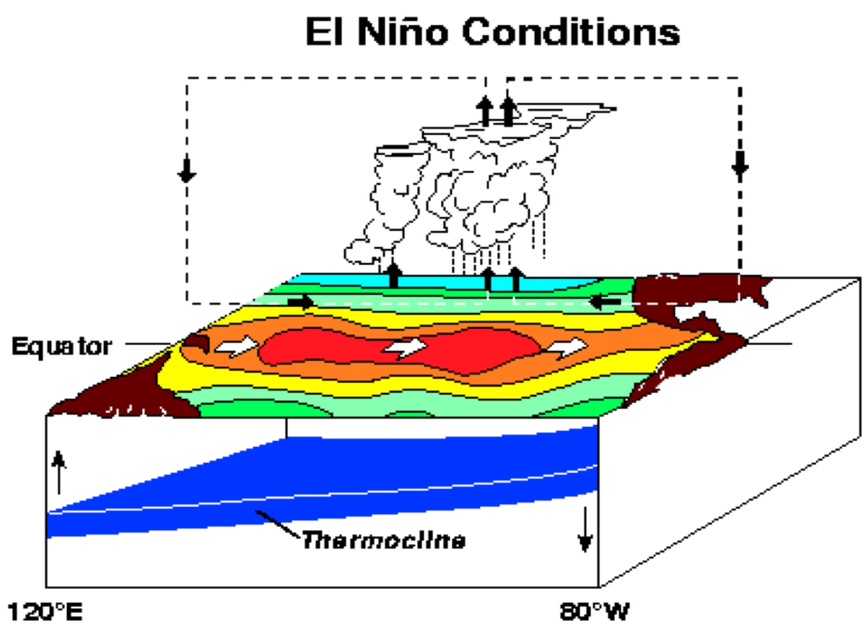


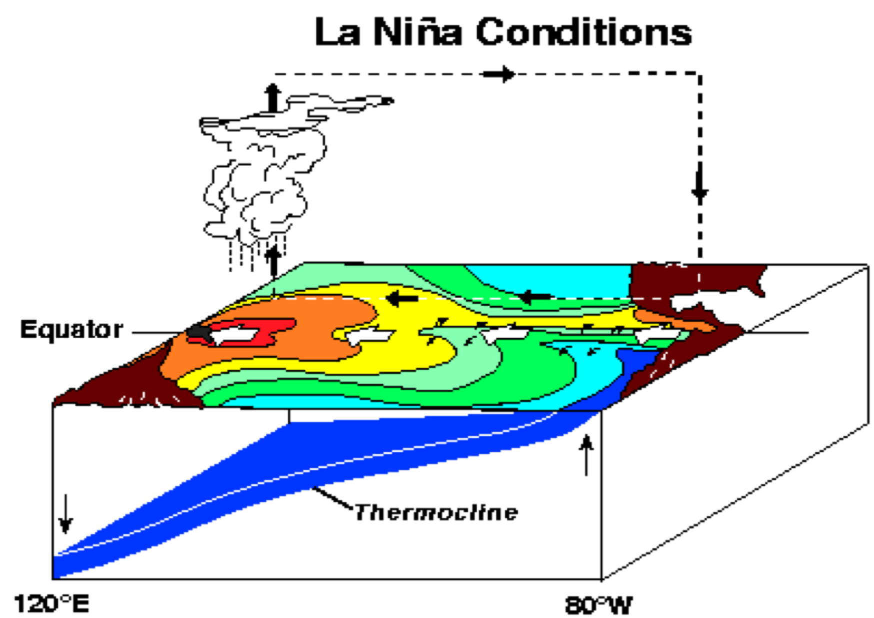
In the equatorial Pacific, there is considerable interannual variability. The EQSOI (EPAC-INDO) is especially useful: it is a measure of pressure shifts in the tropical atmosphere and is more representative than the usual SOI (Darwin–Tahiti). Note the high correlation between EQSOI and NINO3.4 SST index.

The basis for seasonal forecasting

- The feature that gives longer potential predictability is the ocean (and maybe slow boundary changes associated with snow cover, soil moisture, sea ice..).
- The ocean has a large heat capacity and slow adjustment times relative to the atmosphere.
- Ocean variability can give rise to enhanced atmospheric predictability if we are dealing with processes that depend on both media interacting.
- The coupling between the atmosphere and ocean is believed to be quite strong in the equatorial region, viz. ENSO.

How ENSO works in a nutshell





El Niño is associated with reduced easterly winds at the surface, a reduced thermocline slope and warm water in the east. Convection moves to the east.

La Niña is associated with stronger easterly winds at the surface, a stronger thermocline tilt and cold water in the east.

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Basis for Empirical Modelling (1)

- Material presented here taken from Mason & Baddour (2006).
- Empirical (statistical) models provide a much cheaper alternative approach to seasonal climate forecasting to using dynamical models.
- Empirical methods aim to identify relationships between two or more sets of variables through statistical analyses performed on the historical records of the data known as time series. The sets of variables are of two categories:

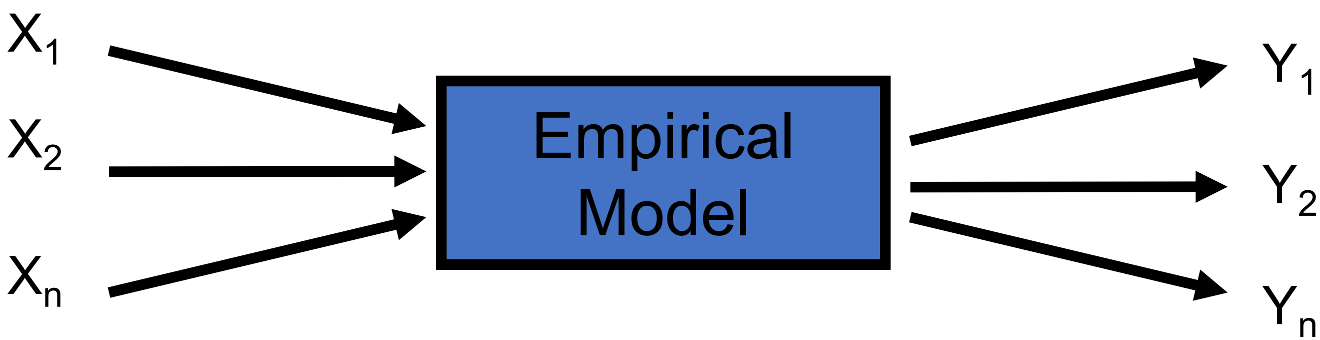
Mason & Baddour (2006) *Empirical Modelling,* in Understanding and Adapting to Climate Variability (eds Troccoli et al) , NATO ASI series, Springer.

Basis for Empirical Modelling (2)

- The sets of variables are of two categories:

1. Variables used to make the predictions (often denoted X), and called *predictors* or explanatory/independent variables. Examples are: SSTs and atmospheric indices (e.g., Southern Oscillation Index - SOI).
2. Variables to be predicted (often denoted Y), and called *predictands* or response/dependent variables. Examples are: seasonal total rainfall and monthly average maximum and minimum temperatures.

Basis for Empirical Modelling (3)



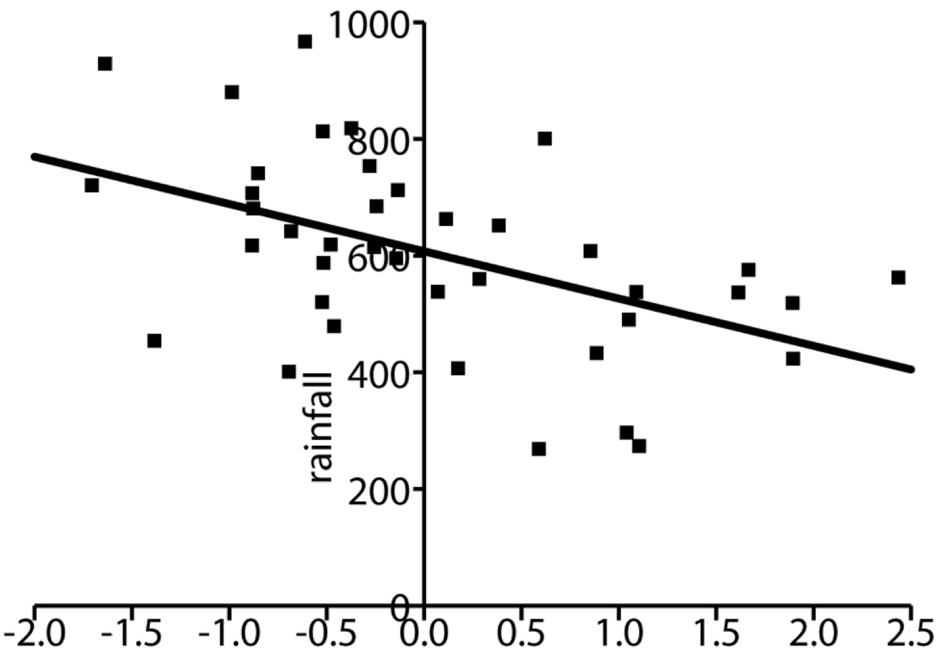
Though normally there is only one predictand.

- Predictions are made on the assumption that these historically observed relationships are expected to apply in the future.
- Because of the possibility of identifying spurious relationships between the predictors and the predictands, the empirical model should be tested carefully on independent data.

Empirical Models

- Most empirical models are based on linear regression
- Modifications to the linear model can be made or alternative statistical procedures used when there is good reason to expect a relationship to be non-linear.
- However, other weaknesses of linear regression may also require these alternatives to be considered seriously. The primary problems with linear regression are multiplicity, multicolinearity, and non-normality of the predictands.
  - Multiplicity refers to the effects of having a large number of candidate predictors: the danger of finding a spurious relationship increases.
  - Multicolinearity arises when more than one predictor is used in the model, and there are strong relationships between the predictors, and can result in large errors in calculating the parameters of the model.
  - A linear regression model may not be adequately constructed if the data being predicted have a strongly skewed or otherwise non-gaussian distribution (e.g, seasonally accumulated precipitation).

Example of empirical relationship



Example of a linear regression model in which October values of the Niño3.4 index are used to predict December - February 1971–2000 rainfall totals for Lusaka, Zambia. The solid line represents the regression model. Mason (2006).

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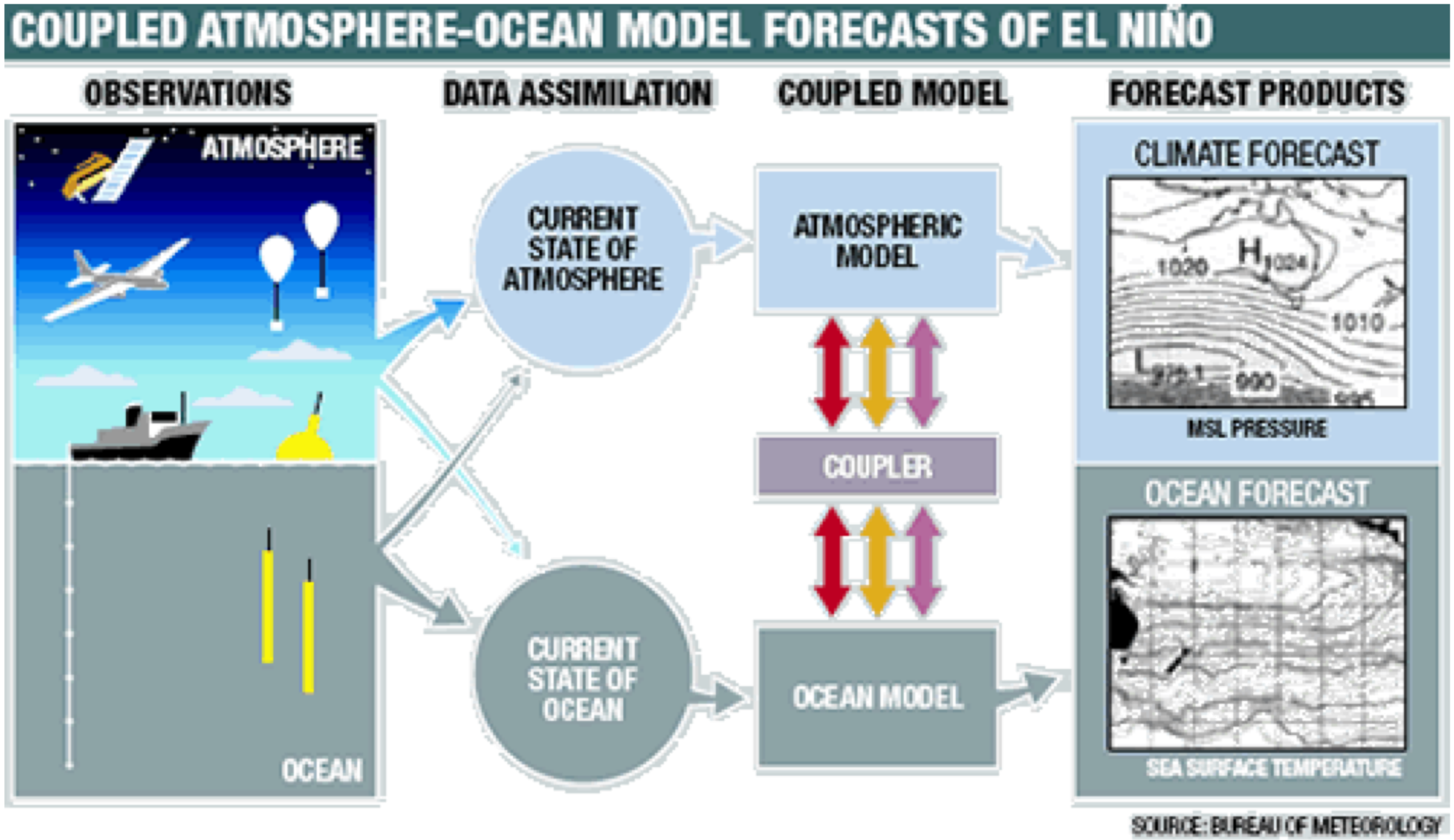
Seasonal Forecast System Ingredients

A coupled model forecast needs 4 key ingredients:

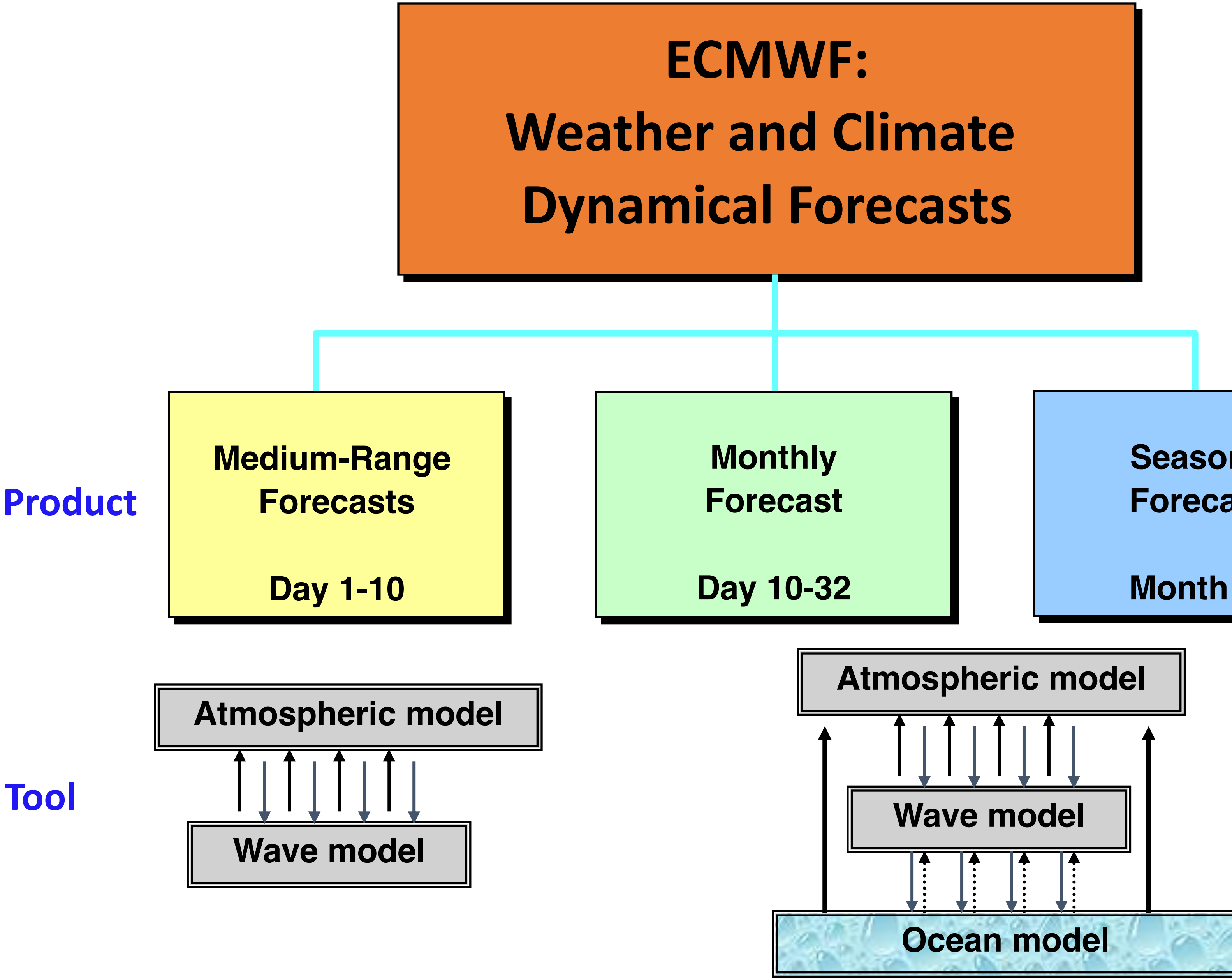
1. An ocean model, complete with a means of creating the initial conditions (ocean analysis, data assimilation)
2. An atmospheric model, complete with a means of creating the initial conditions
3. A coupled model consisting of the atmosphere and ocean communicating regularly
4. A strategy for calculating and evaluating the forecasts

Any forecast is of necessity a **probability forecast** (as opposed to a deterministic one) though this is often overlooked. How do we create probability forecasts and how do we evaluate them is key.

Seasonal Forecasting System in a nutshell



Courtesy Bureau of Meteorology, Australia.


ECMWF:
Weather and Climate
Dynamical Forecasts
Product
Medium-Range
Forecasts
Day 1-10
Monthly
Forecast
Day 10-32
Seasonal
Forecasts
Month 2-6
Tool
Atmospheric model
Wave model
Atmospheric model
Wave model
Ocean model

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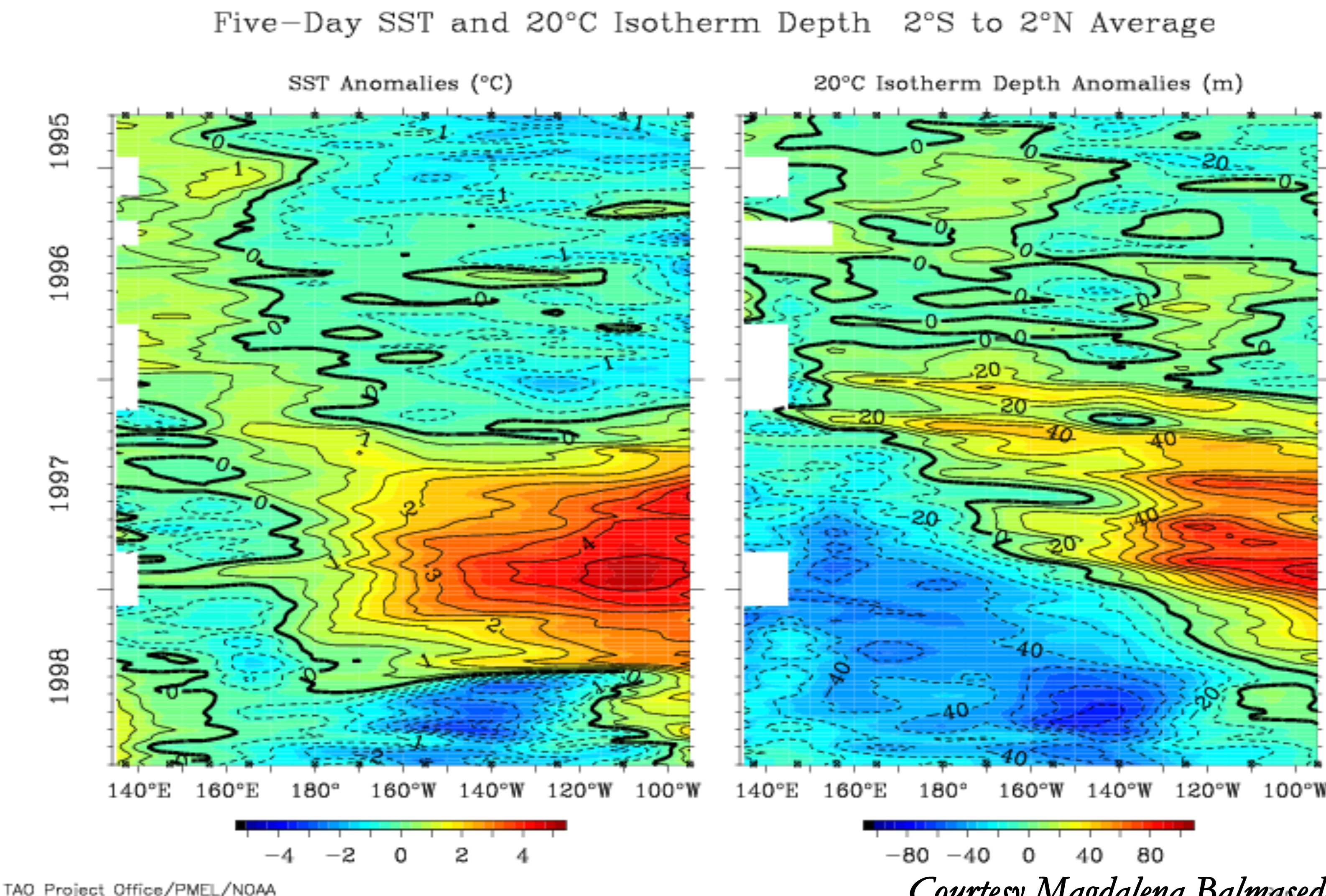
Signal at the surface (left) generally lags behind the subsurface signal (right) → need to initialize the subsurface of the ocean

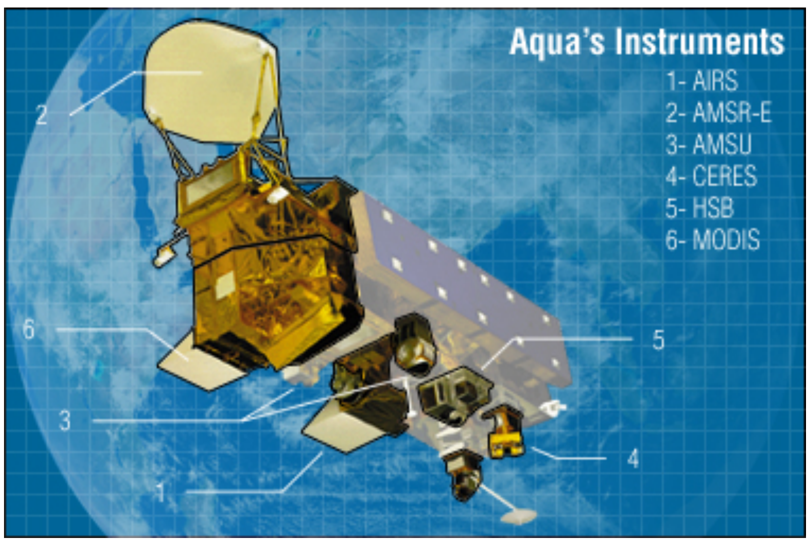


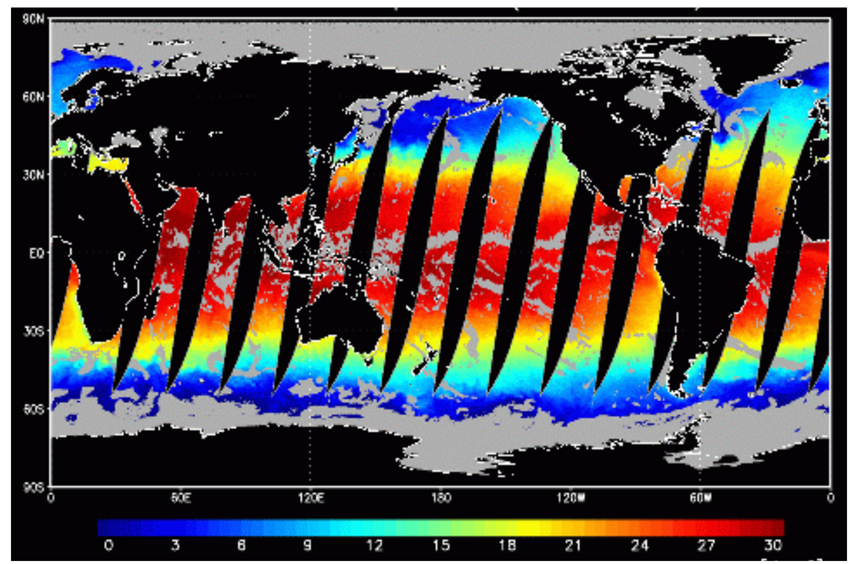
Courtesy Magdalena Balmaseda, ECMWF

Atmosphere-Ocean Interface: Sea Surface Temperature

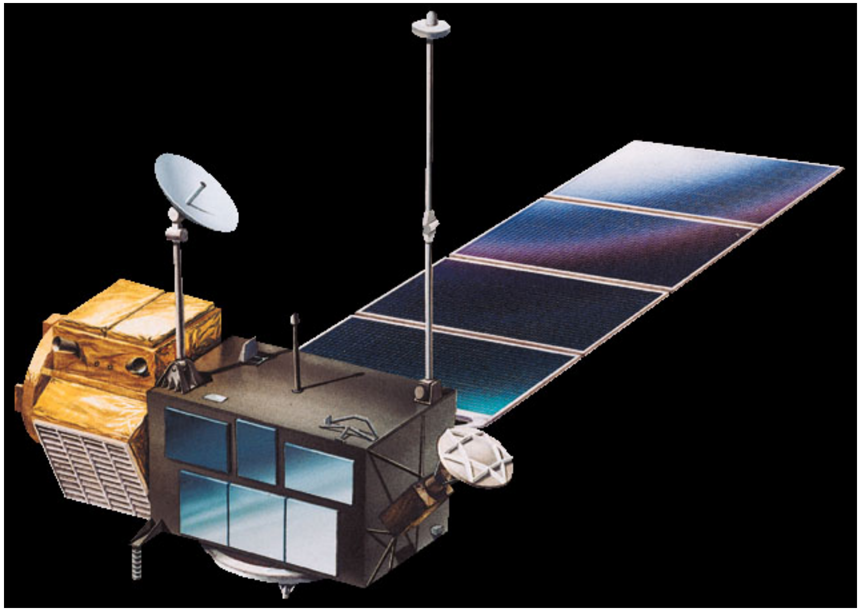
The most important quantity at the Atmosphere-Ocean interface is the Sea Surface Temperature (The SST)

- See e.g. the GODAE High Resolution Sea Surface Temperature for a new generation of global, multi-sensor, high-resolution (~6 hours and 10 km), SST products http://www.ghrsst-pp.org/

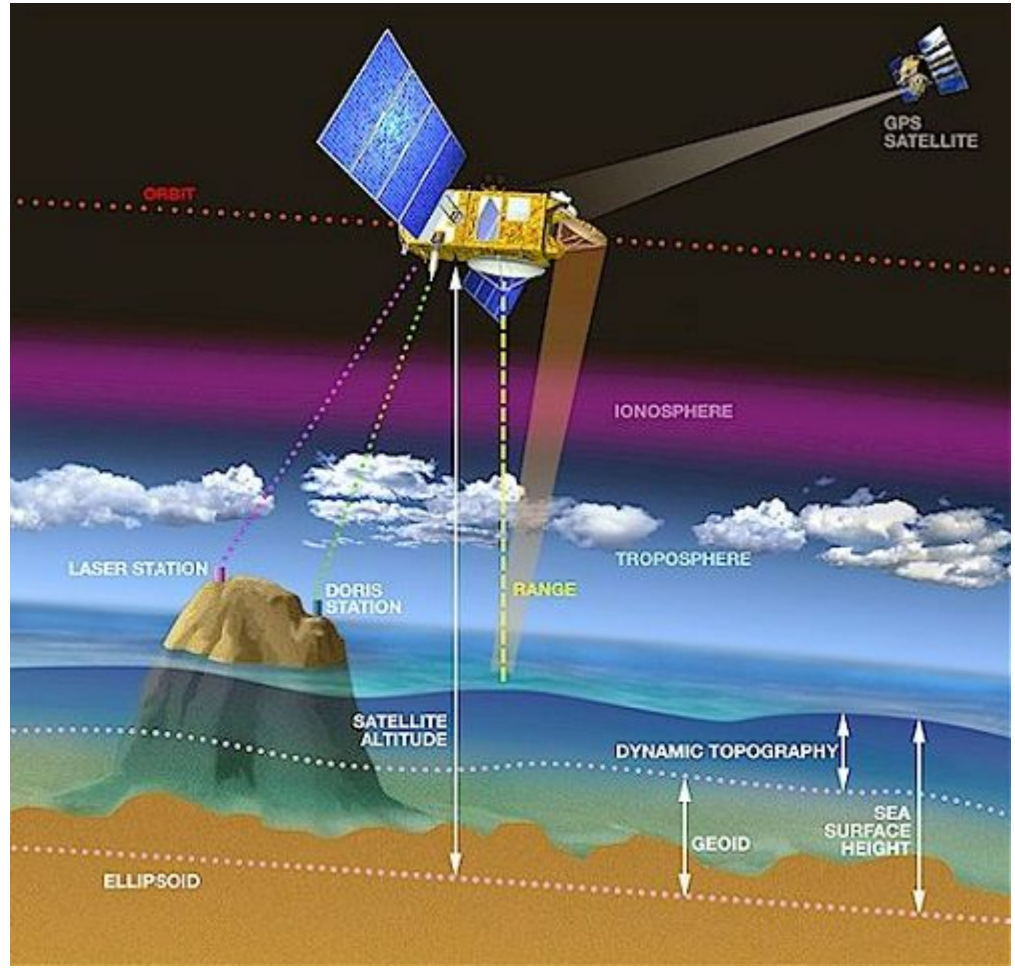




Measuring Sea Surface Height from Space



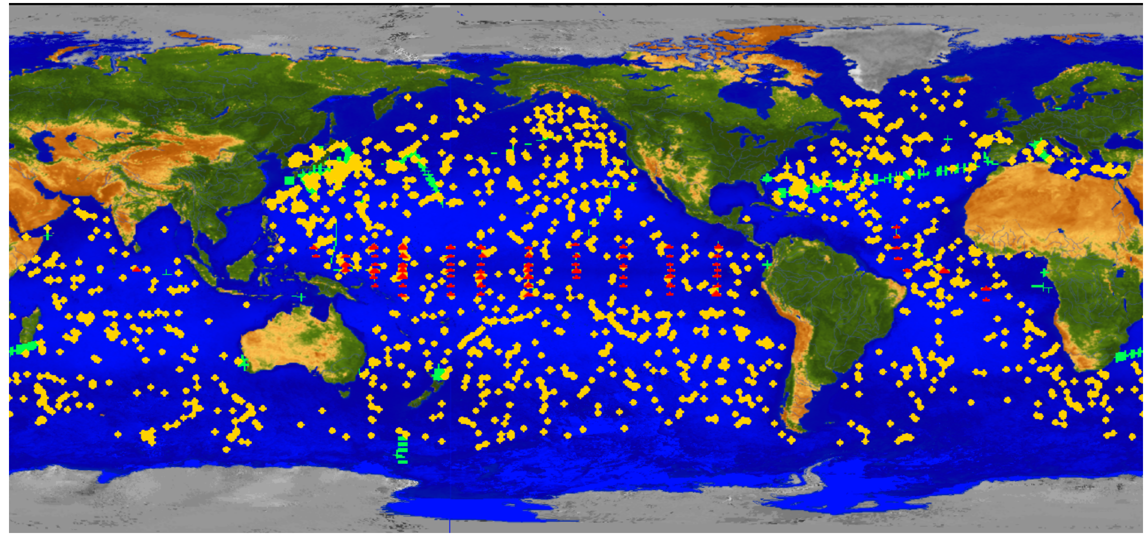
Altimetry missions measure the sea level with reference to the ellipsoid and not to the geoid (the mass distribution of the Earth). Hence, we only have a sea level anomaly (not an absolute value). Geodetic missions are already underway, however.



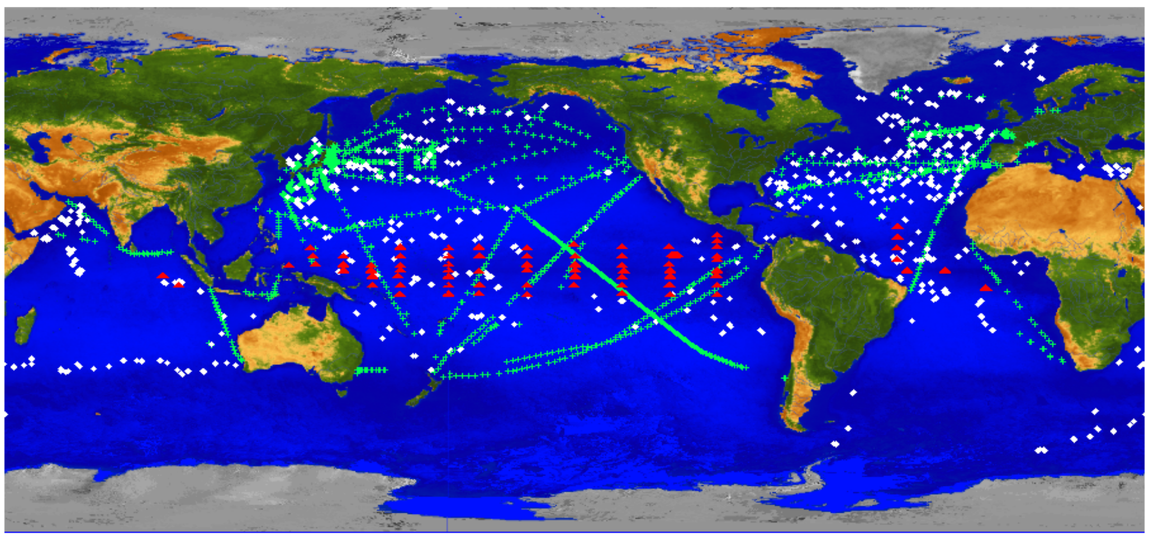
Courtesy JPL (NASA, USA) web site

Oceanic subsurface observations

Coverage for Feb 2005



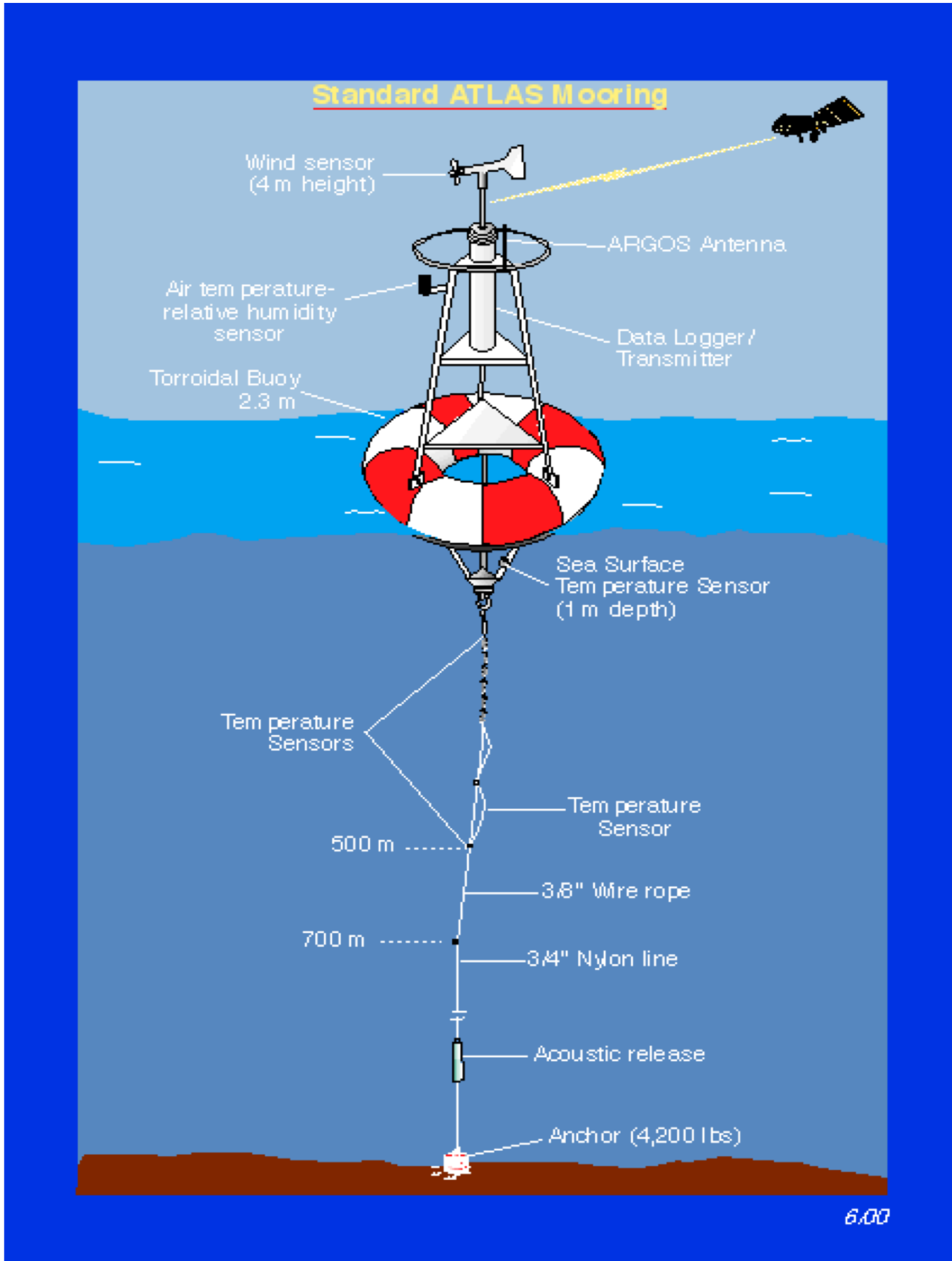
Coverage for May 2002



XBT, MOORINGS,

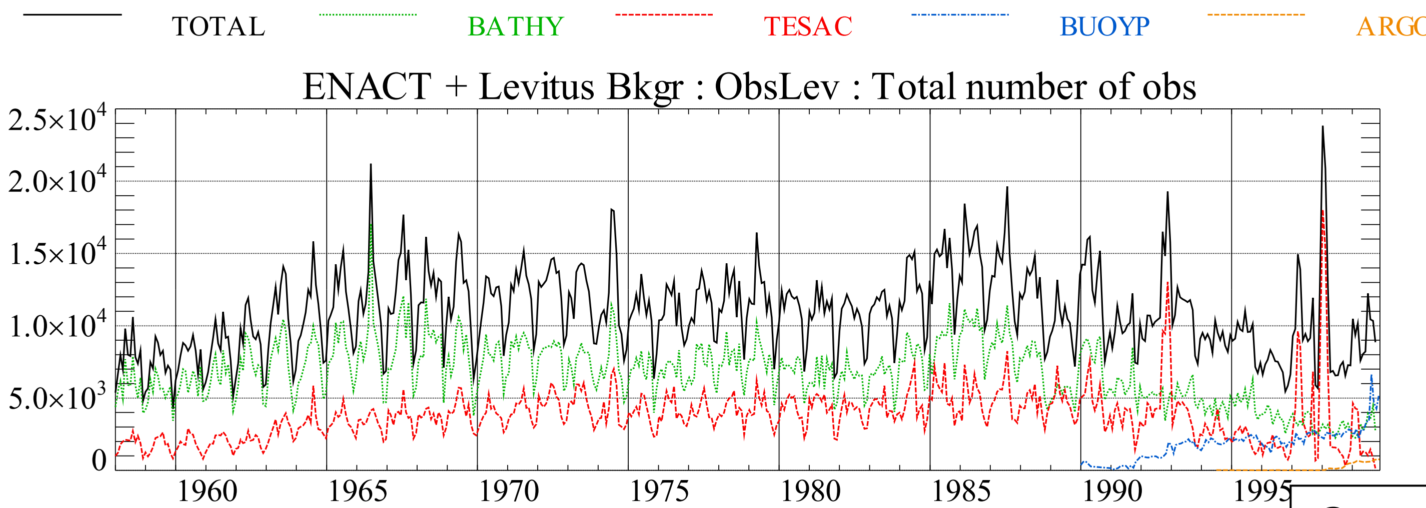
ARGO floats

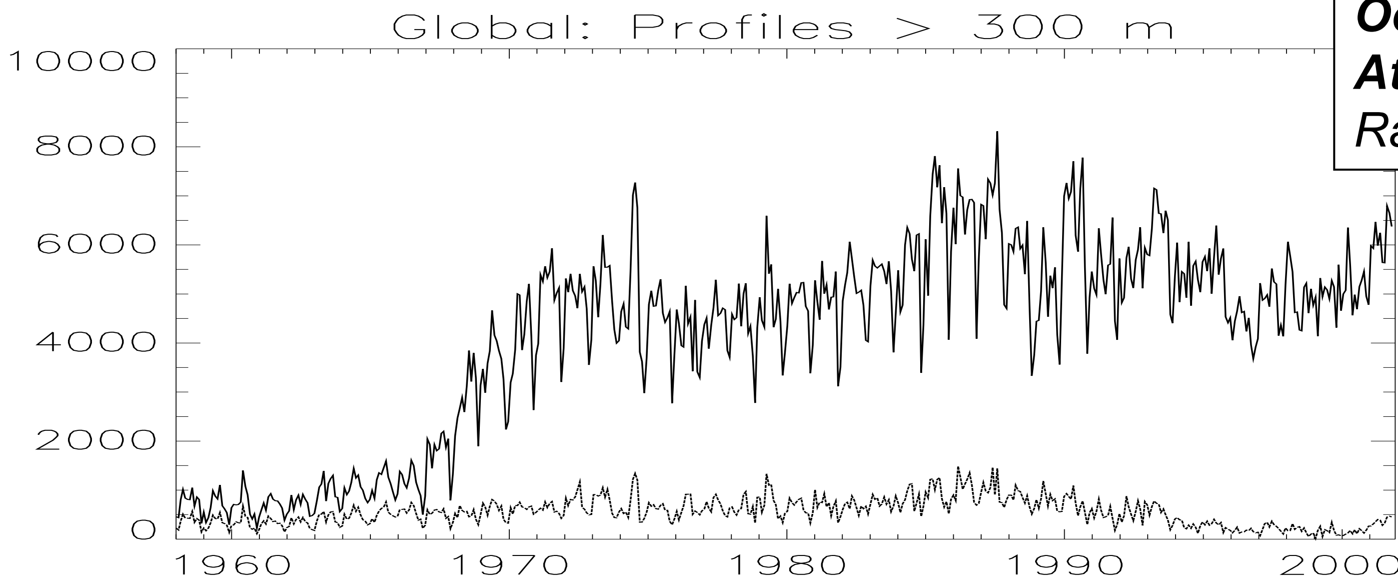
Courtesy Arthur Vidard, INRIA



Atlas moorings are the backbone of the equatorial ocean observing system. They measure temperature at 10 depths from the surface to 500m. The data are transmitted via satellite and are on the GTS within a few hours.

In situ Observations in the Ocean





Ocean ~ 10,000 obs/mth
Atmo ~ 9·106 obs/mth
Ratio ~ 1/ 1,000

Courtesy Bruce Ingleby (UK Met Office)

New ECMWF operational ocean re(analysis)

Basic (existing) Setup:

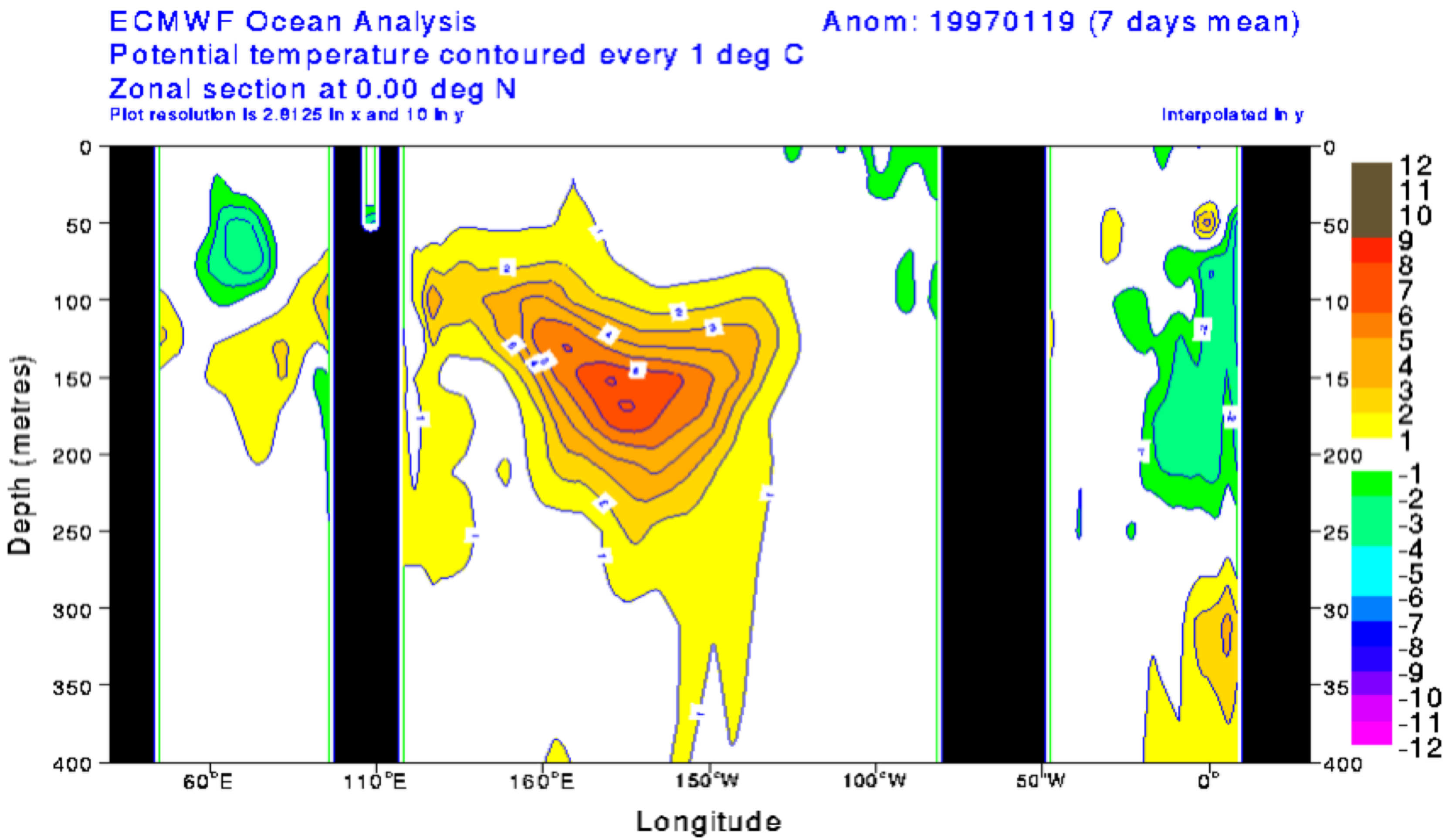
- Ocean model: HOPE (~1x1 going to 1x.3 at the equator)
- Assimilation Method OI
- Assimilation of T + Balanced relationships (T-S, ρ-U)
- 10 days assimilation windows, increment spread in time
- Ensemble of 5 ocean analyses to represent uncertainty

System-3

+New Features

- ERA-40 fluxes to initialize ocean
- Retrospective Ocean Reanalysis back to 1959.
- Multivariate on-line Bias Correction .
- Assimilation of salinity data.
- Assimilation of altimeter-derived sea level anomalies.
- 3D OI

Ocean Analysis: Temperature along equator Jan 1997



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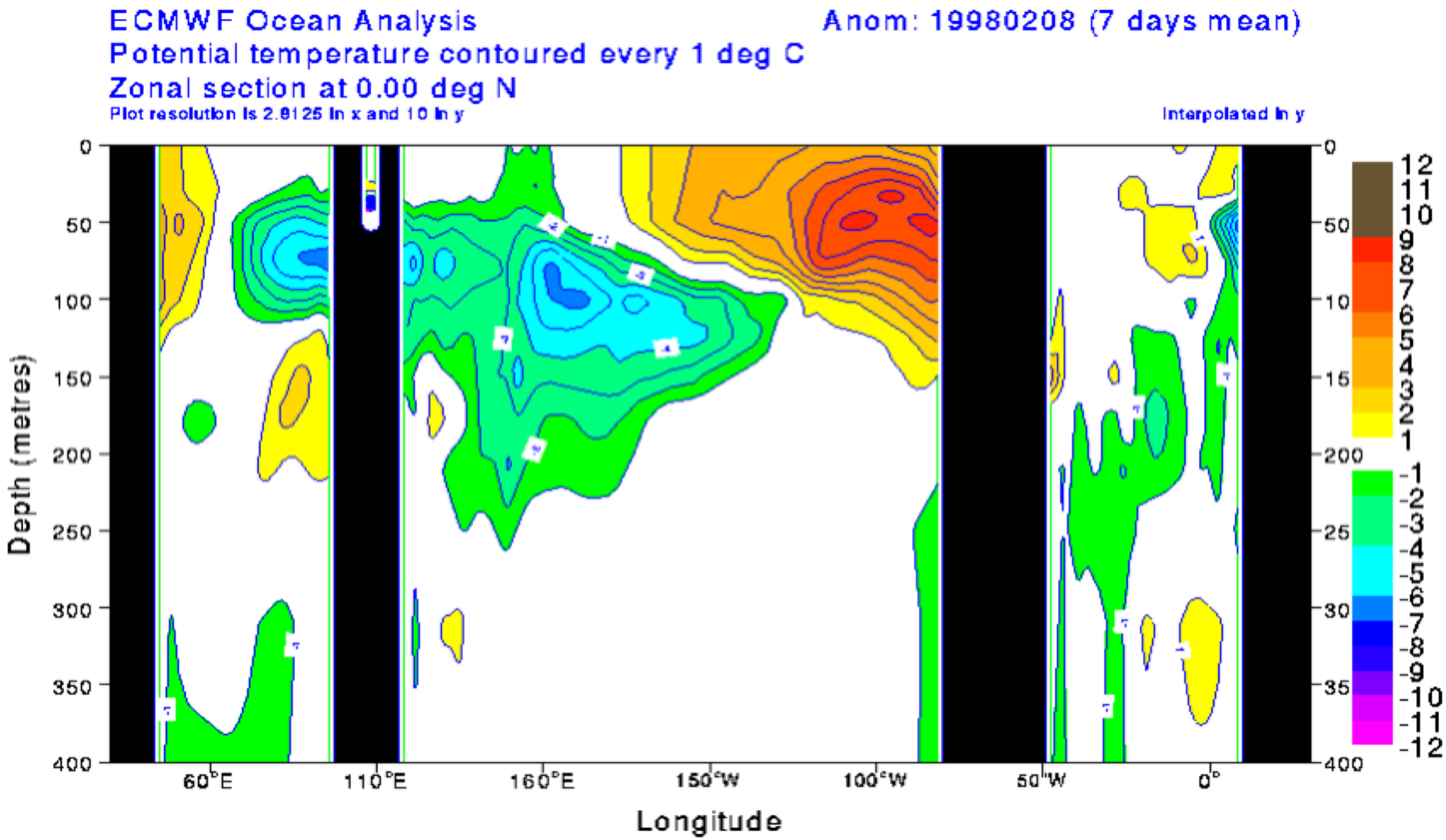
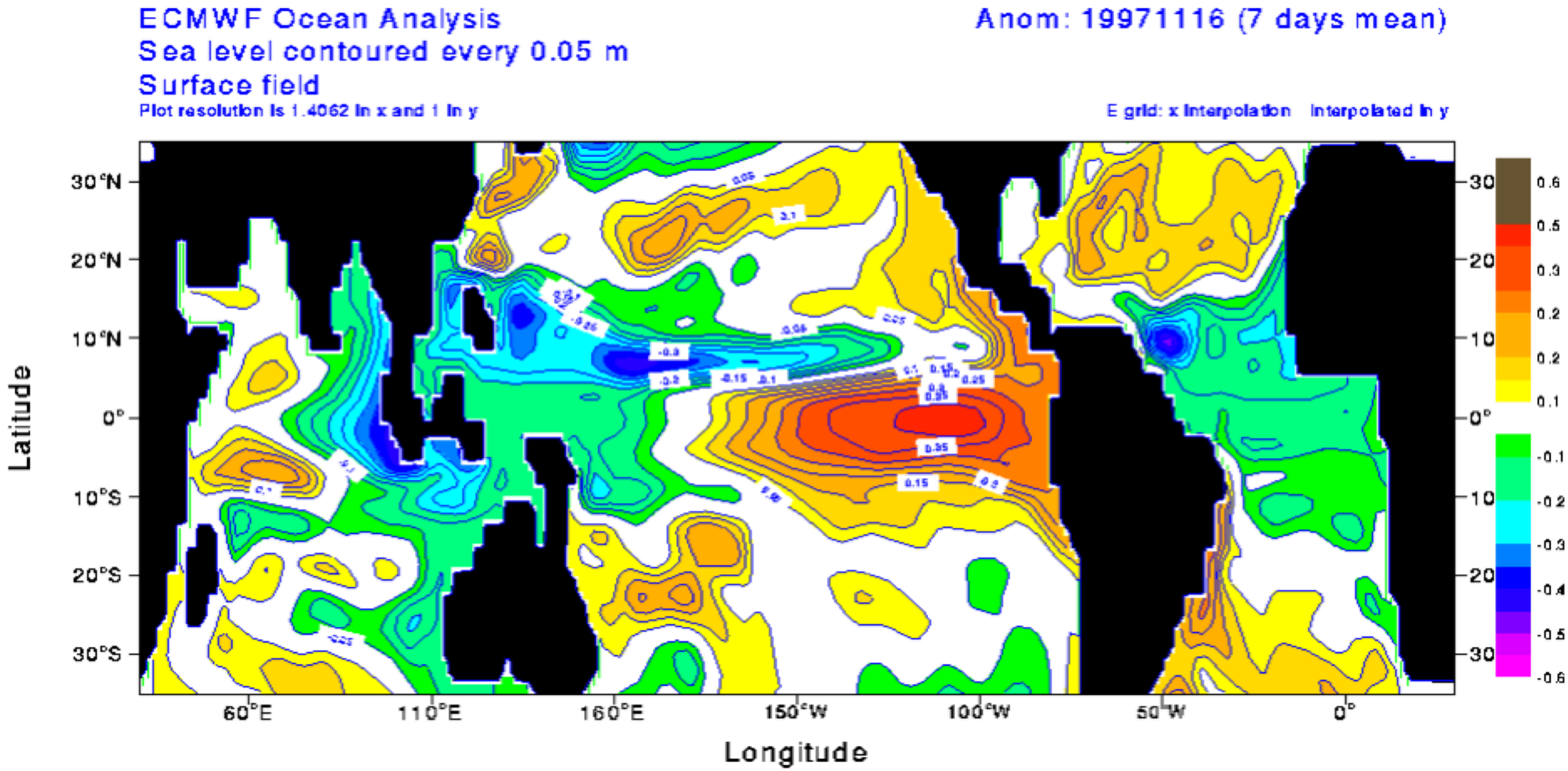
Ocean Analysis: Temperature along equator Feb 1998



Ocean Analysis: Sea level
Nov 1997



ECMWF

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Seasonal forecasting in the world

The ECMWF Seasonal System

System-2 (currently operational)

•COUPLED MODEL

- Atmospheric model cycle 23R4
- Atmospheric resolution TL95 and 40 levels
- Hope ocean model (1x1, 1x0.33 at Equator)
- Oasis-2 coupler

•INITIALIZATION

- ERA-15 data to initialize ocean and atmosphere in hindcasts
- Assimilation of subsurface temperature only
- "Multivariate" corrections to the salinity and velocity fields
- Ensemble of 5 ocean analyses (wind-stress perturb.) back to 1987.

•ENSEMBLE GENERATION

- Real time FC: 40 ensemble members (pos./neg. SST perturbations added to 5 ocean analyses)
- "Stochastic physics" throughout the integrations
- Back integrations:
  - 5 members, 1987-2001 for calibration.
  - 40 members (Nov and May starts) for skill assessment.

System-3
(expected
early 2007)

- COUPLED MODEL
  - New cycle of atmospheric model (Cy31R1)
  - Higher atmospheric resolution TL159 and 62 levels
  - Time varying greenhouse gasses.
  - New sea-ice specification algorithm
  - Include ocean currents in wave model

- INITIALIZATION
  - ERA-40 data to initialize ocean and atmosphere in hindcasts
  - Include bias correction in ocean assimilation.
  - Include assimilation of salinity and altimeter data.
  - Ocean reanalysis back to 1959, using ENACT/ENSEMBLES ocean data

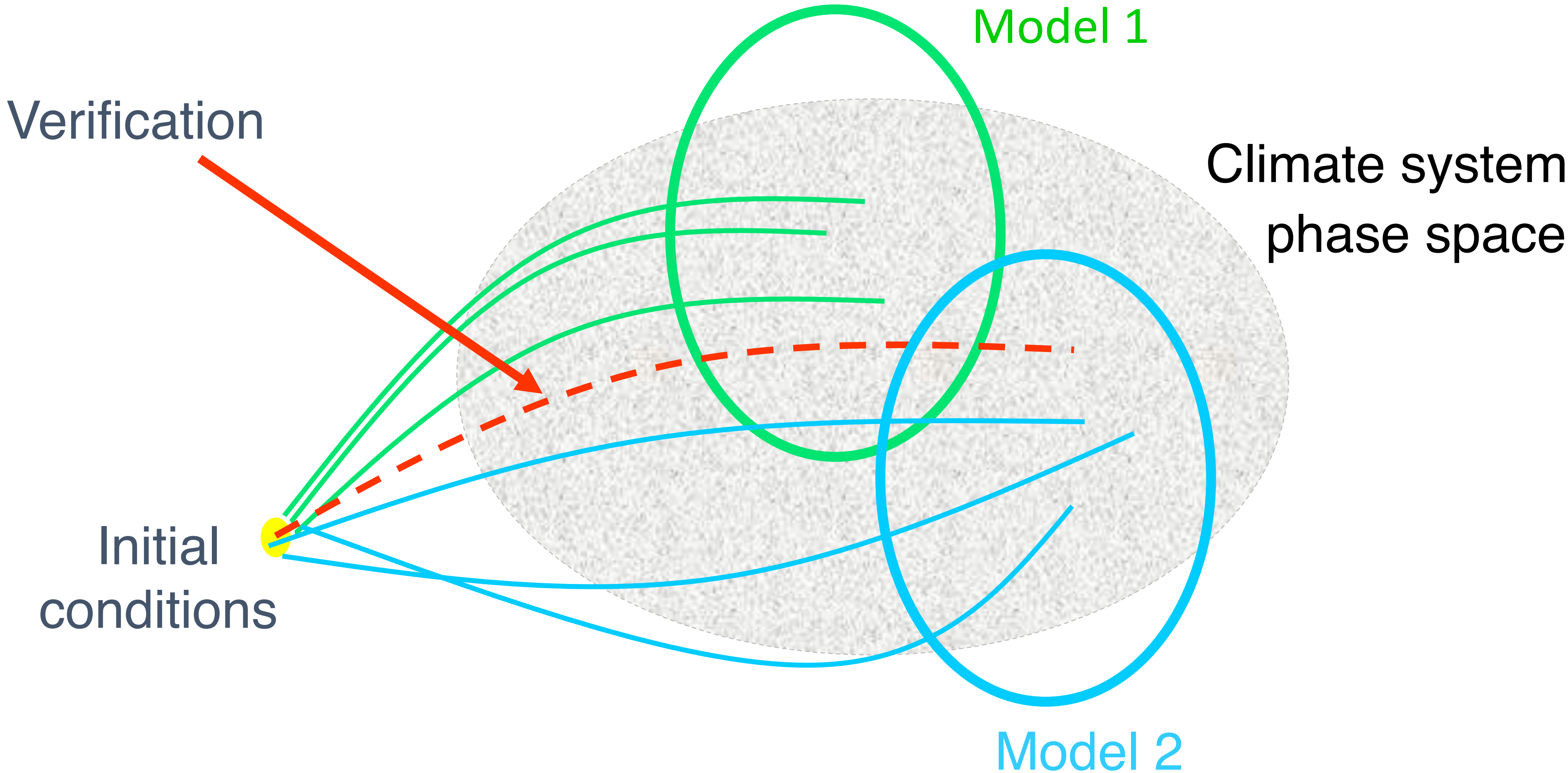
- ENSEMBLE GENERATION
  - Extended range of back integrations: 11 members, 1981-2005.
  - Revised wind and SST perturbations.
  - Use EPS Singular Vector perturbations in atmospheric initial conditions.

- Forecasts extended to 7 months (to 13 months 4x per year).

EUROSIP: European Operational Seasonal-to-Interannual Predictions

- Three coupled seasonal forecast systems:
  - ECMWF (System 2)
  - Météo France (Arpege/OPA)
  - UK Met Office (GloSea)
- Ensemble integrations performed at ECMWF
- Multi-model products to be computed and made available to member states
- Graphical products available on the ECMWF web site
- Data access/distribution policy to be agreed

Multi-Model Ensemble Approach



- To account for error in initial conditions use ensemble concept
- To account for model error use multi-model concept

DEMETER multi-model ensemble system

- DEMETER system: 7 coupled global circulation models

Partner	Atmosphere	Ocean
ECMWF	IFS	HOPE
LODYC	IFS	OPA 8.3
CNRM	ARPEGE	OPA 8.1
CERFACS	ARPEGE	OPA 8.3
INGV	ECHAM-4	OPA 8.2
MPI	ECHAM-5	MPI-OM1
UKMO	HadCM3	HadCM3

4 start dates per year

6 months hindcasts

9 member ensembles

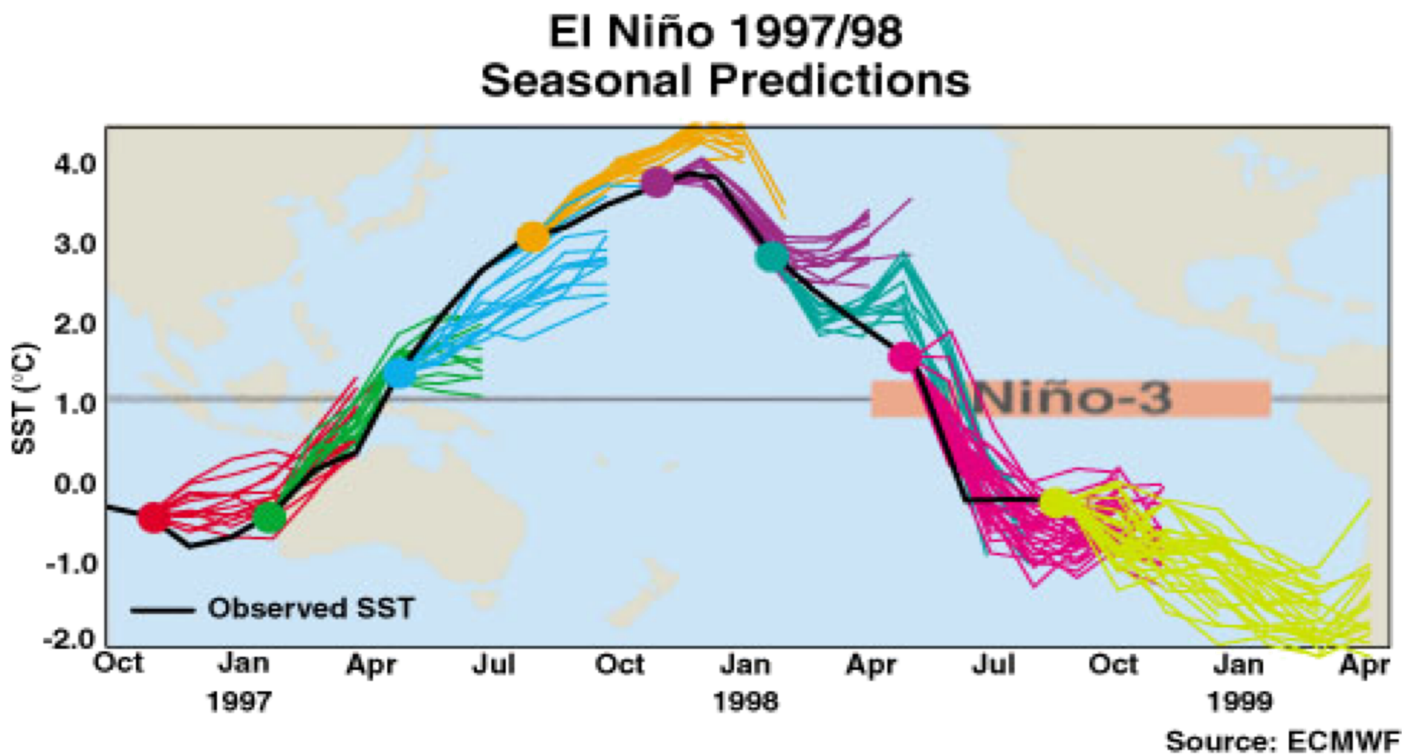
3 ocean analyses, 4 ±SST pert

ERA-40: ocean forcing and atmospheric initial conditions

- Hindcast production for: 1980-2001 (1958-2001)

http://www.ecmwf.int/research/demeter/

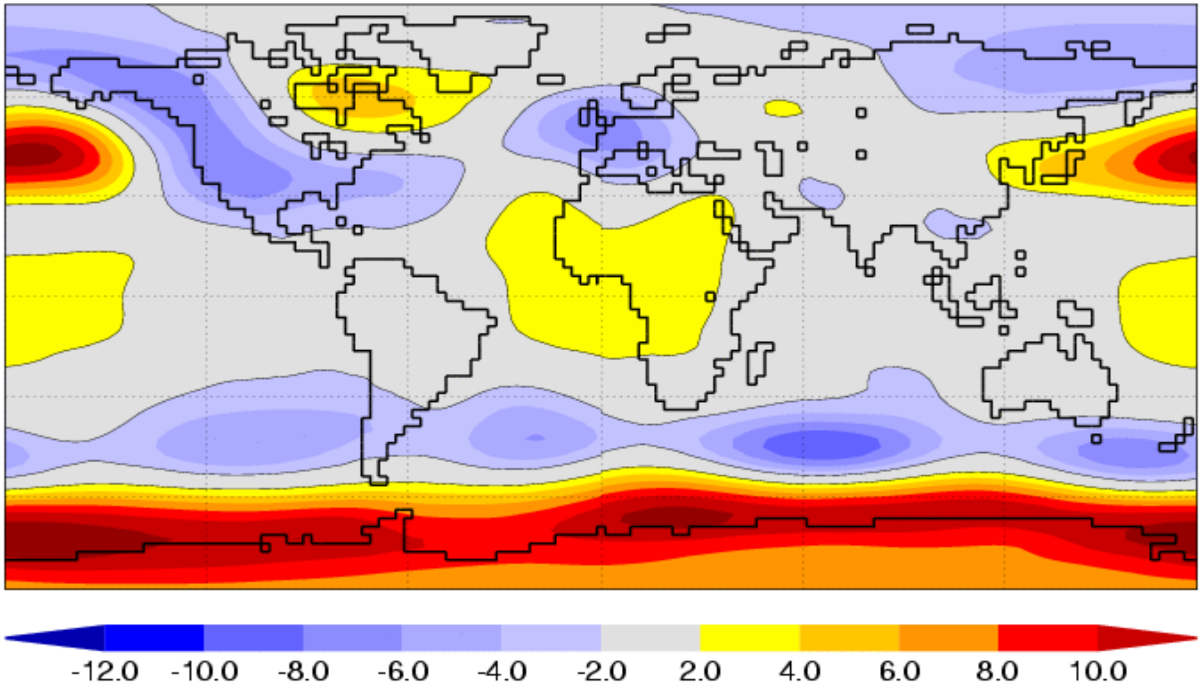
Seasonal forecasts: Niño 3 plumes



Niño plumes are often the first forecast one looks at. However, before doing so post-processing steps have to be followed in order to take into account of model errors via the so-called calibration.

Sources of errors in seasonal forecasting systems

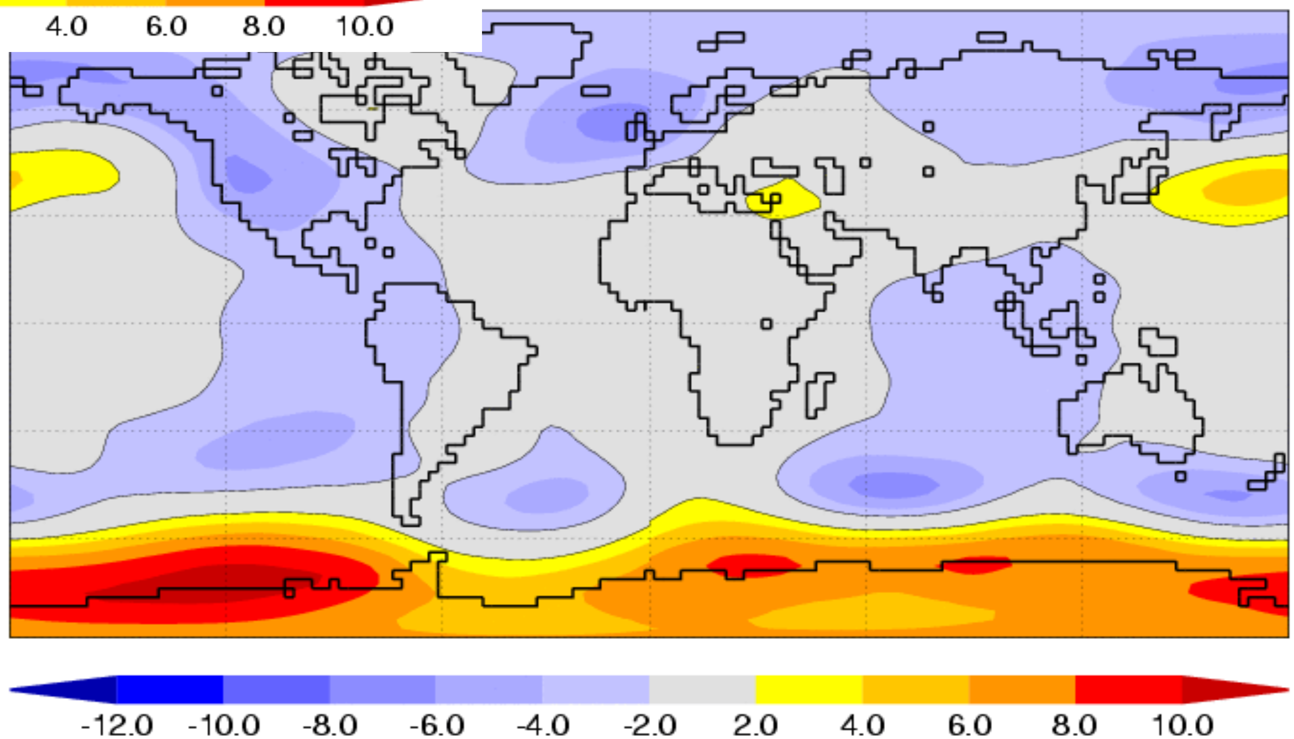
- Errors in **boundary forcing** during ocean analysis
  - momentum fluxes perturbed to give ocean analysis ensemble
- Errors in **initial state** of ocean for forecasts
  - Perturb SSTs and possibly observations in data assimilation
- Errors in the **model** components
  - Significant **model errors** in ocean, atmosphere, land and ice
    - Subtract the model forecast climatology to get anomaly forecasts – bear in mind that errors may not be stationary
    - ENSEMBLES (EU project) is exploring ensemble design (stochastic physics, perturbed physics) http://www.ensembles-eu.org/
    - Multi-model (cf. EUROSIP, ~5000 years of GCM f/c)



Systematic errors in atmospheric fields: 500-hPa geopotential height in JFM (m.4-6)

System 3

System 2



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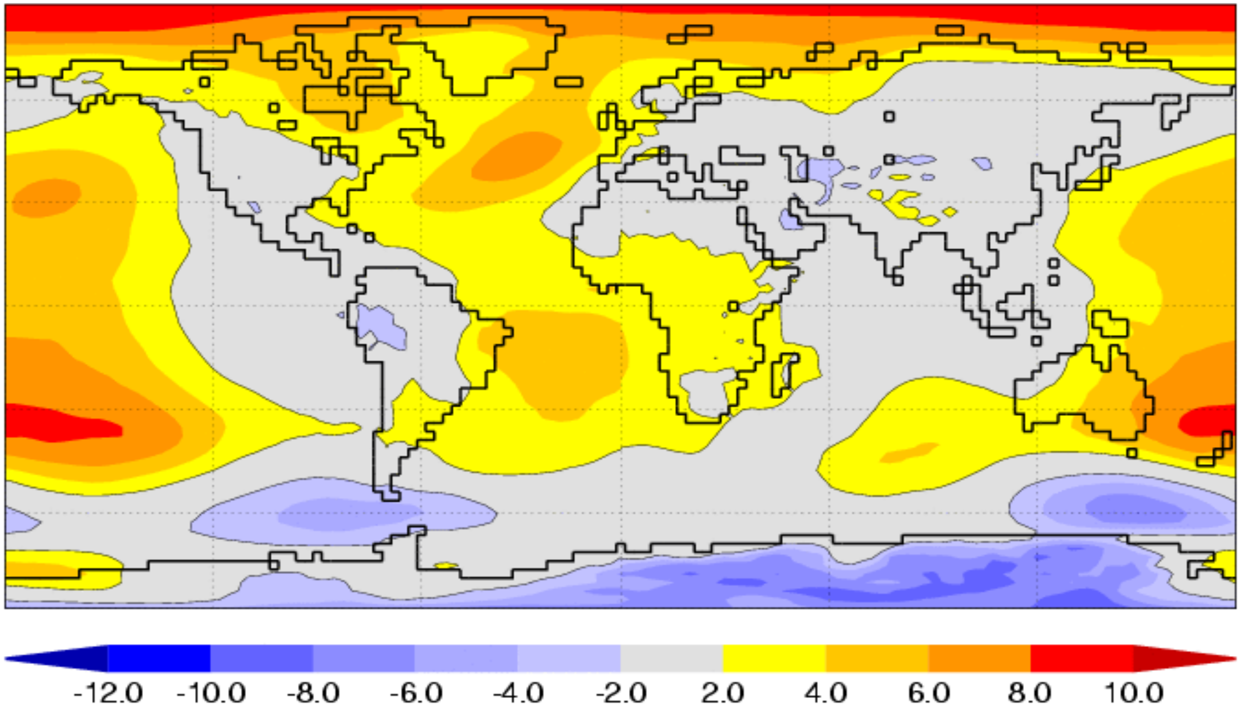
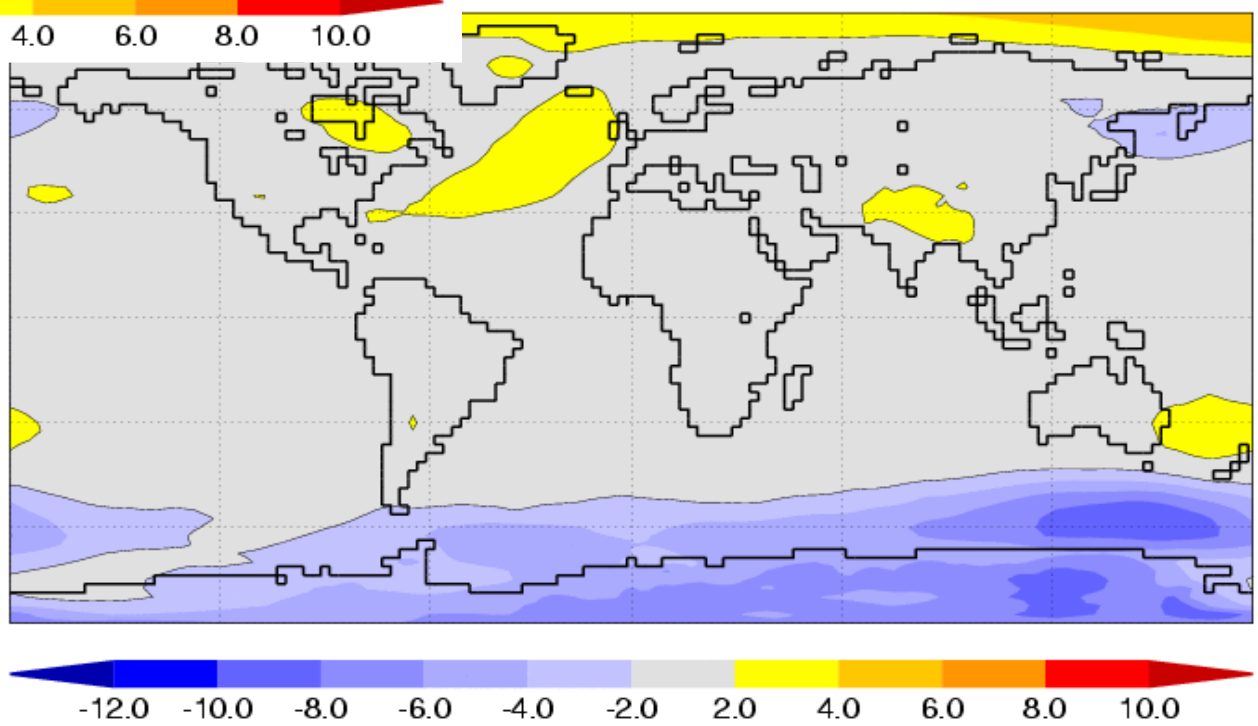
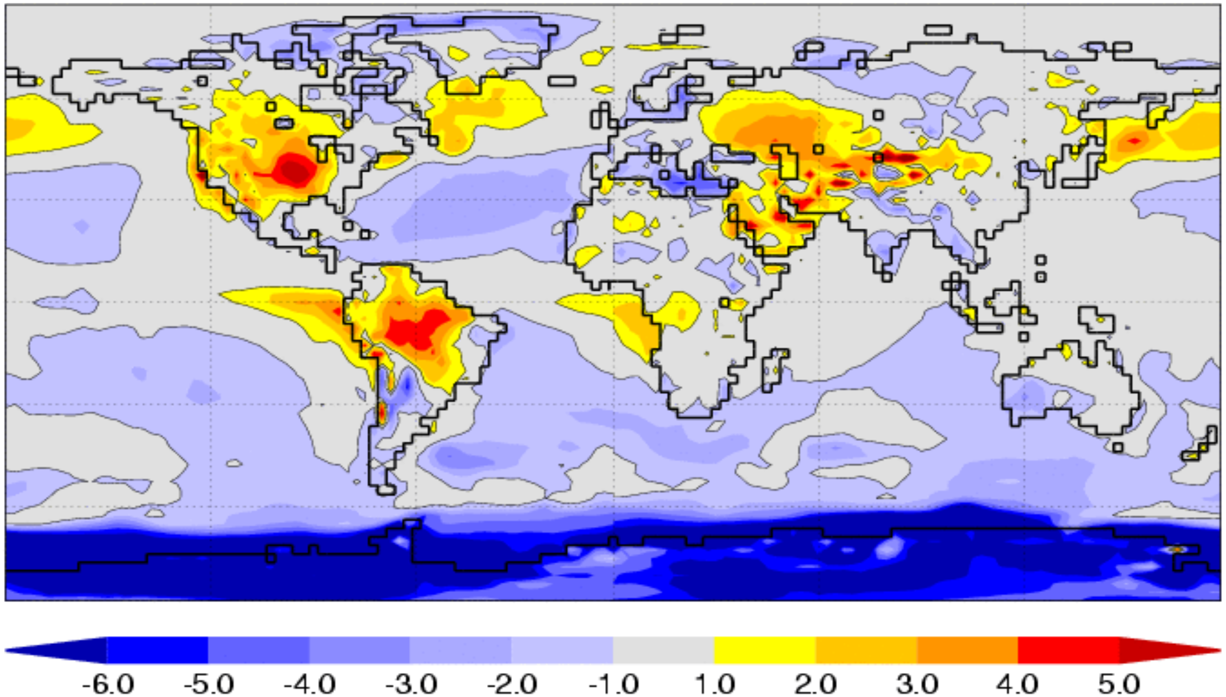


System 3

System 2

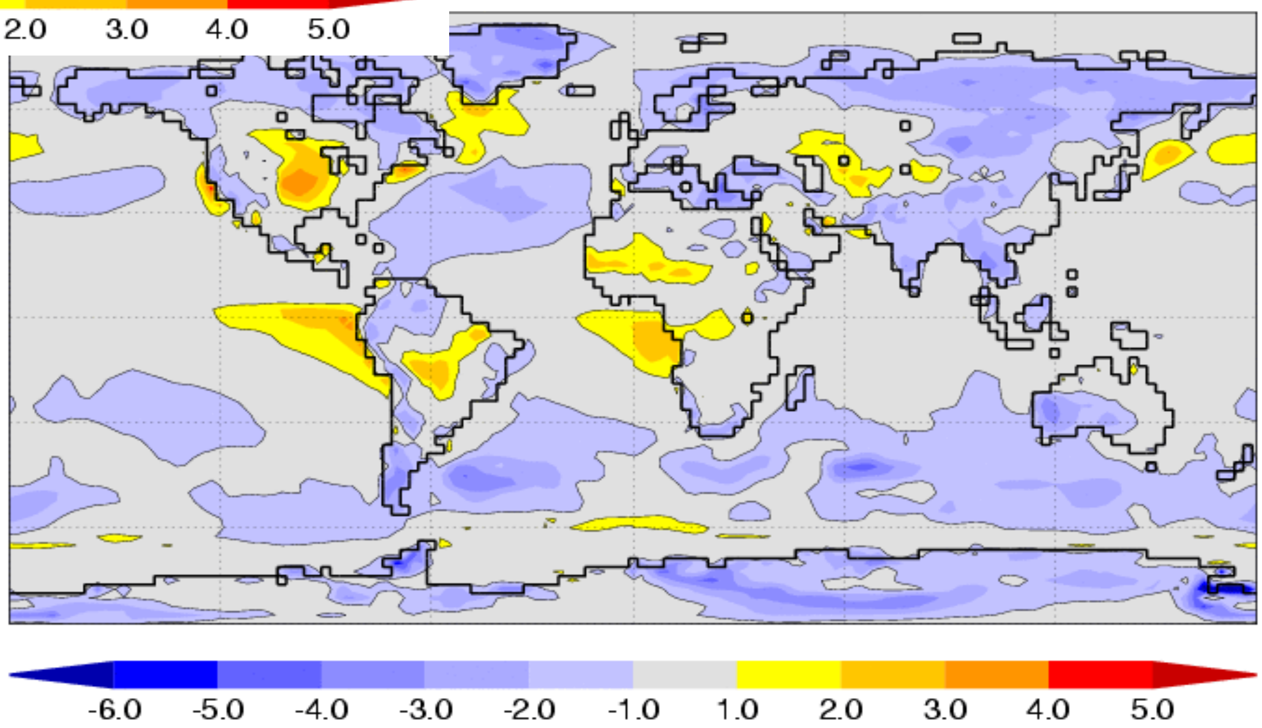


Systematic errors in atmospheric fields: 2-m. temperature in JAS (m.4-6)

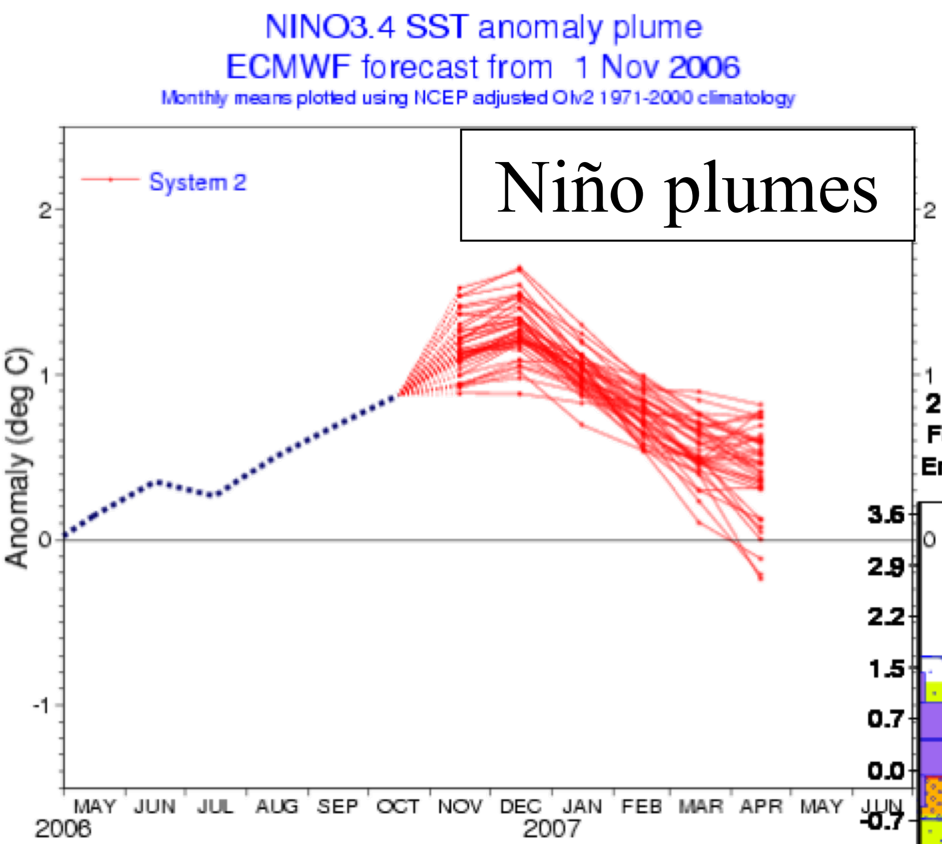


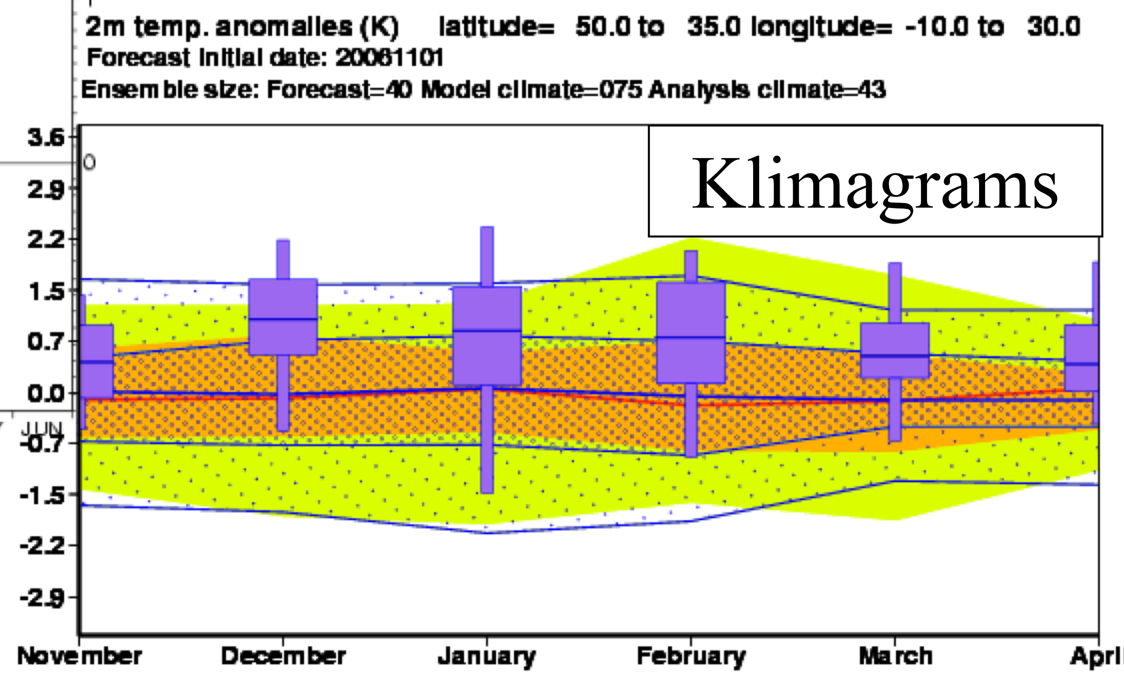
System 2

System 3



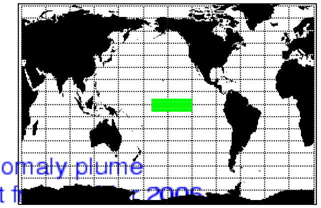
Seasonal Forecast products

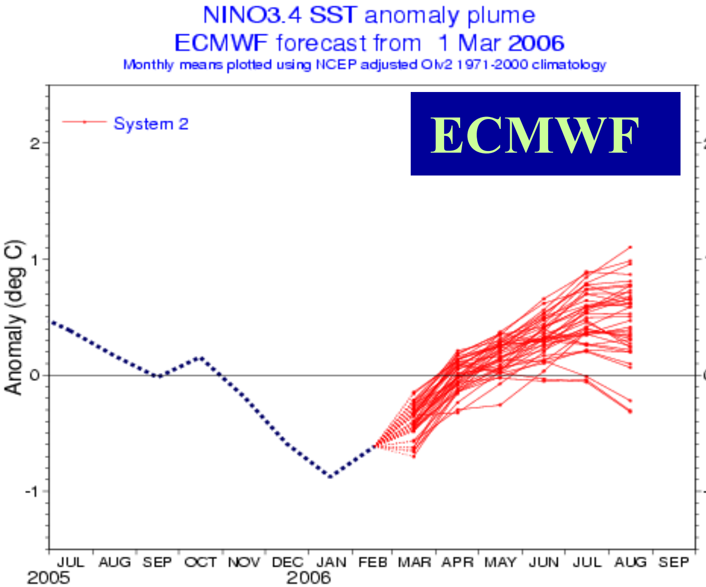


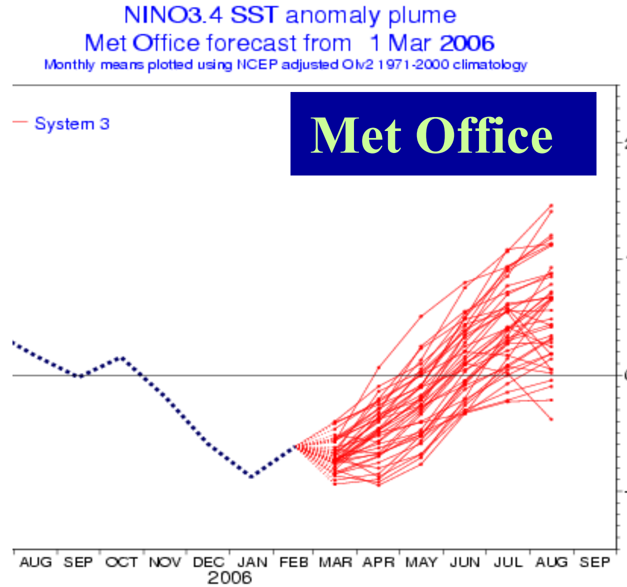


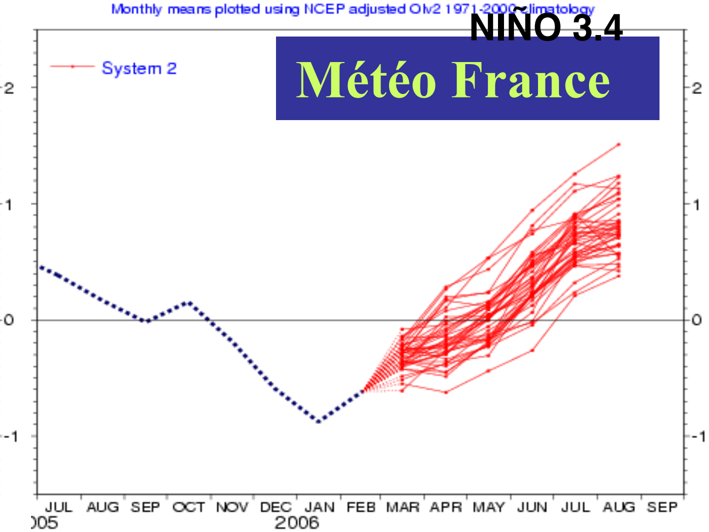
ECMWF

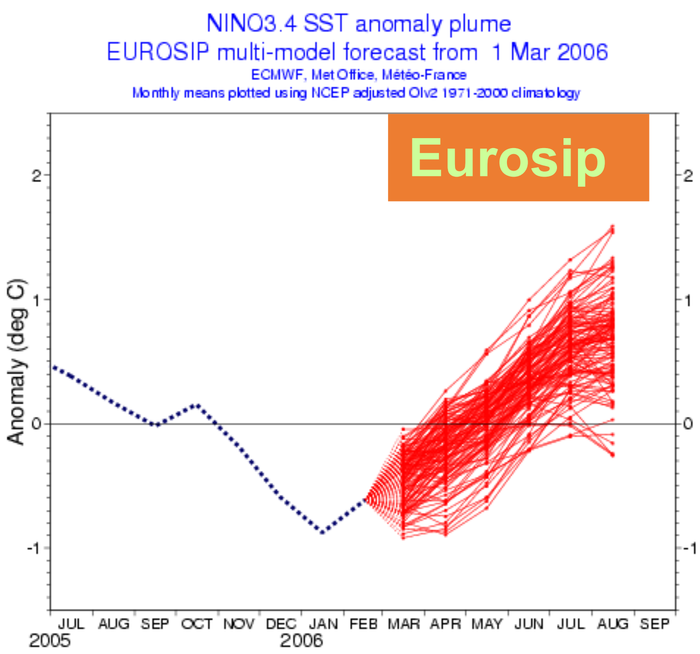
Example Niño 3.4 Forecast for Multi-model

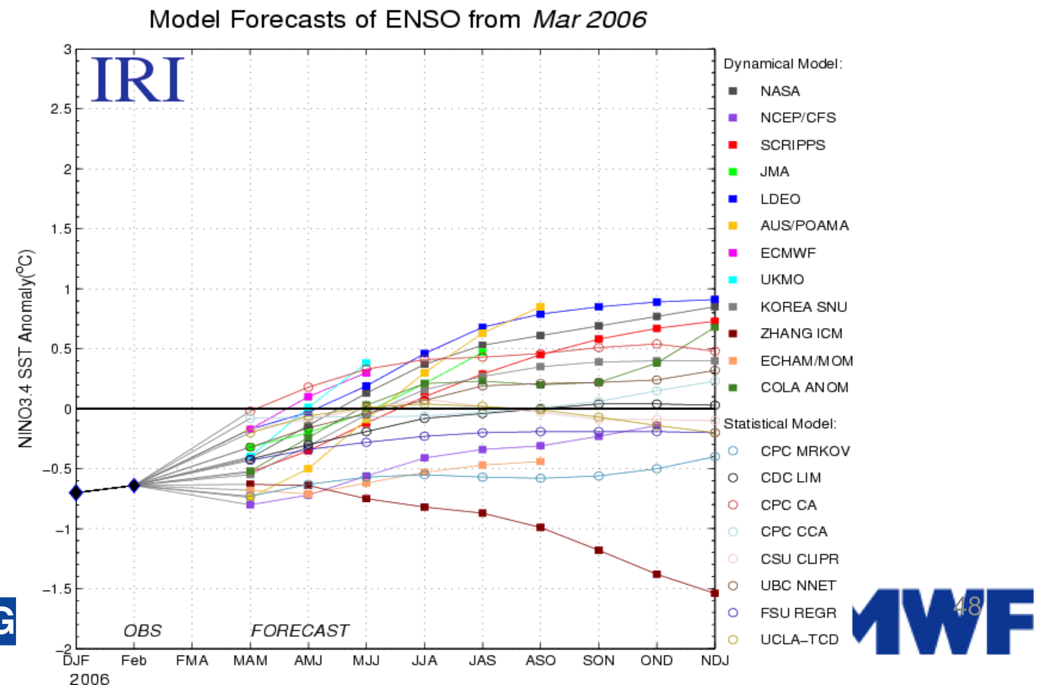




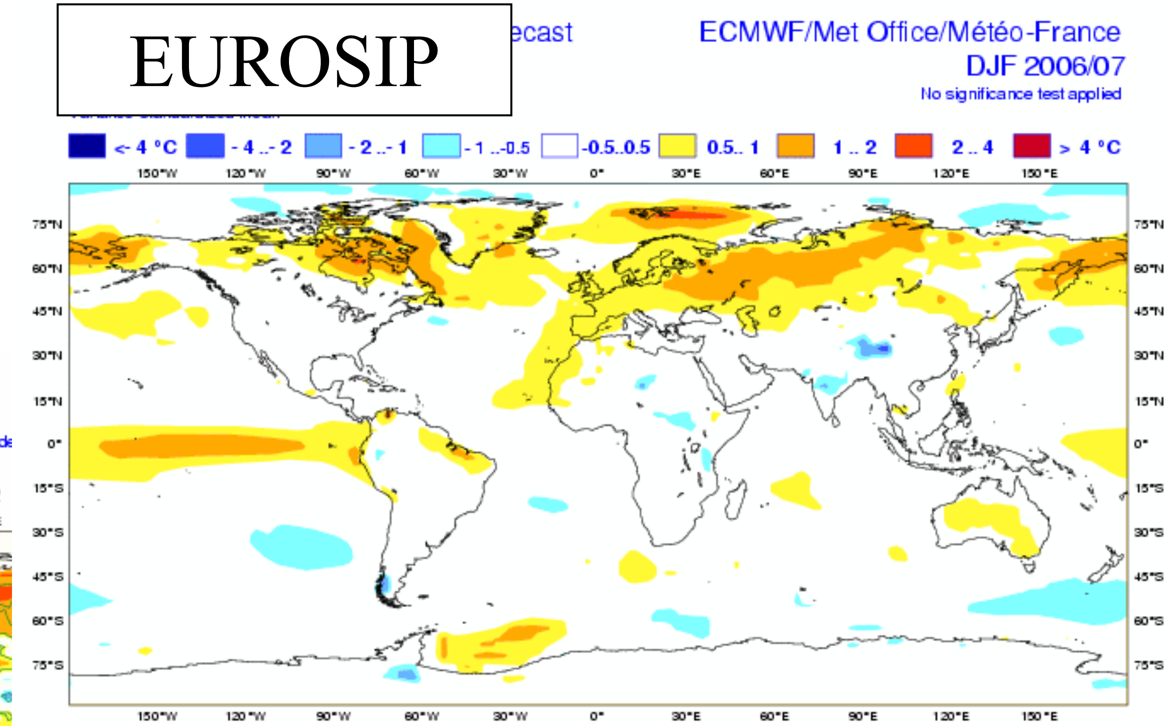


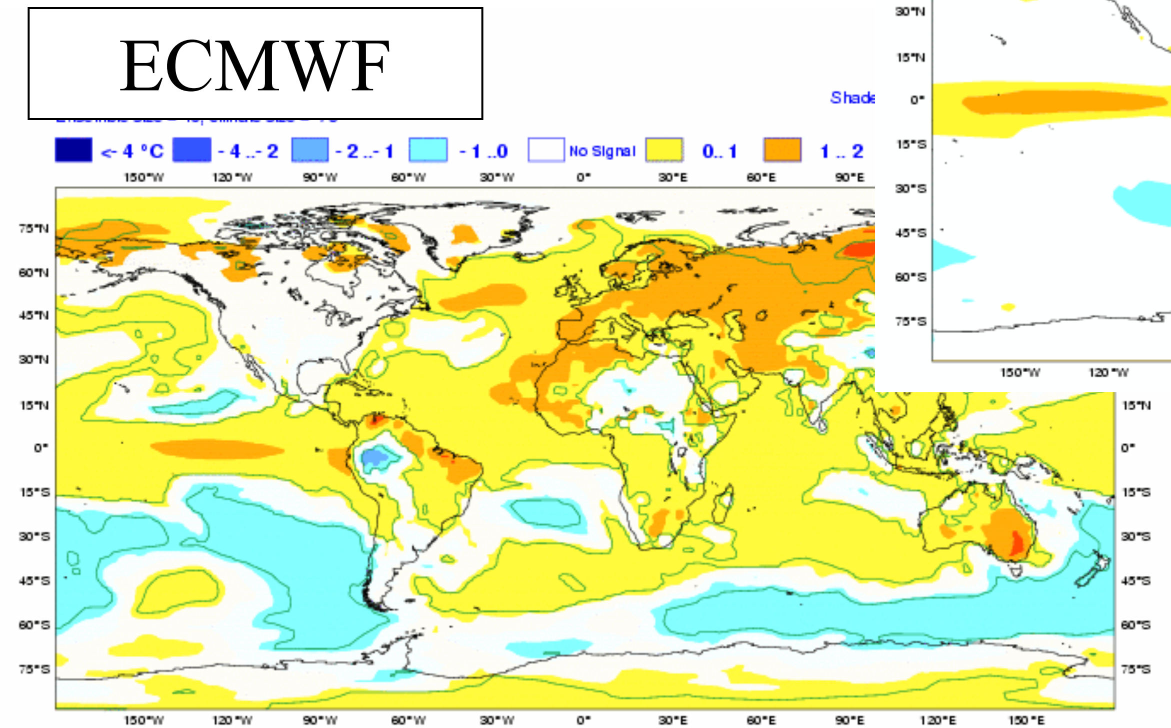






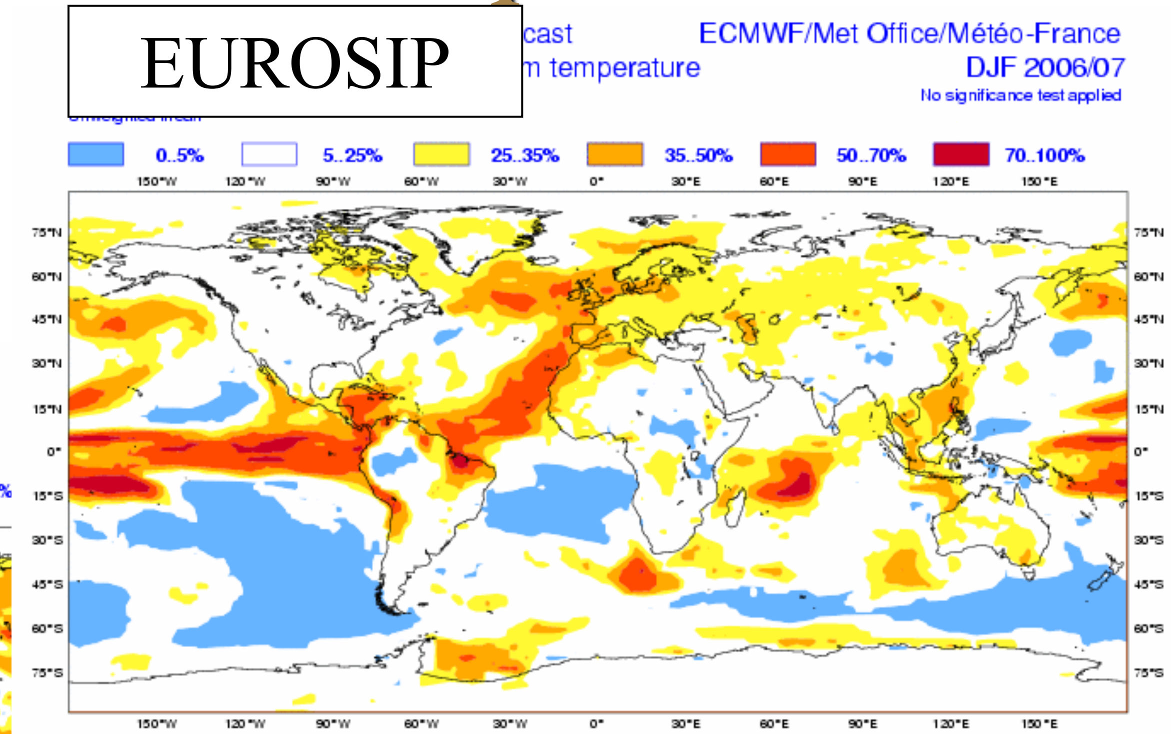
Seasonal Forecast products:
Mean 2m Temperature anomaly

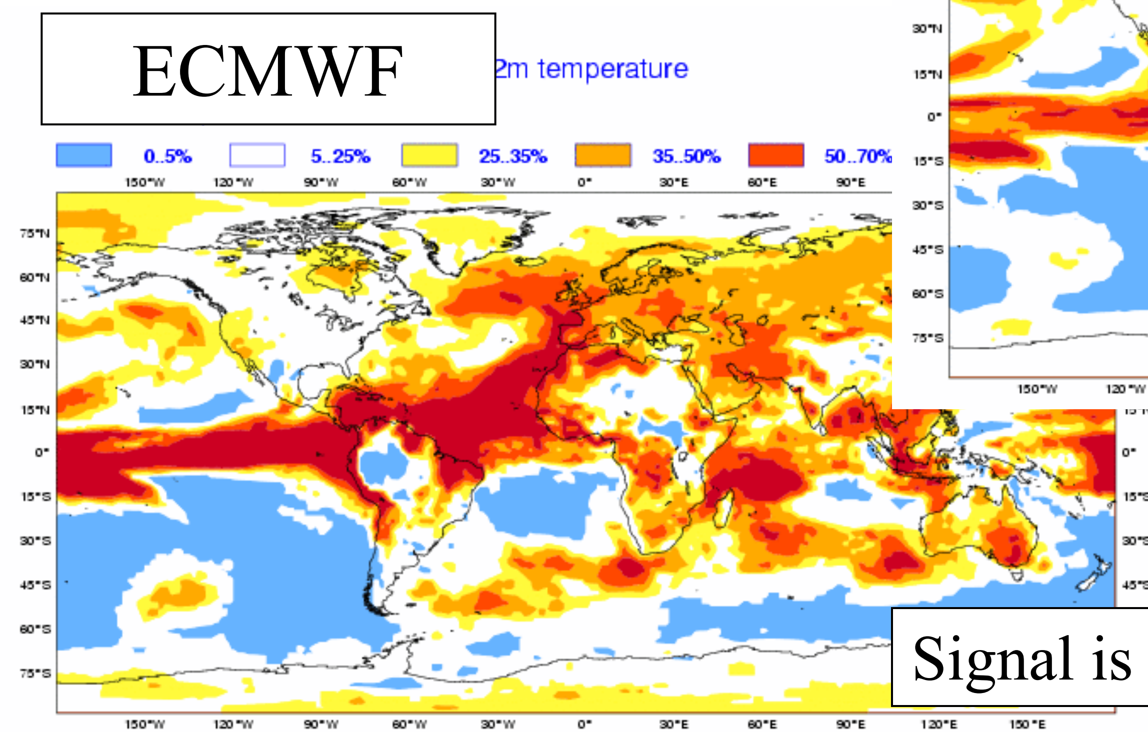




General agreement between single model and multimodel anomaly patterns but size smaller in multimodel.

Seasonal Forecast products: Upper 15% for 2m Temperature

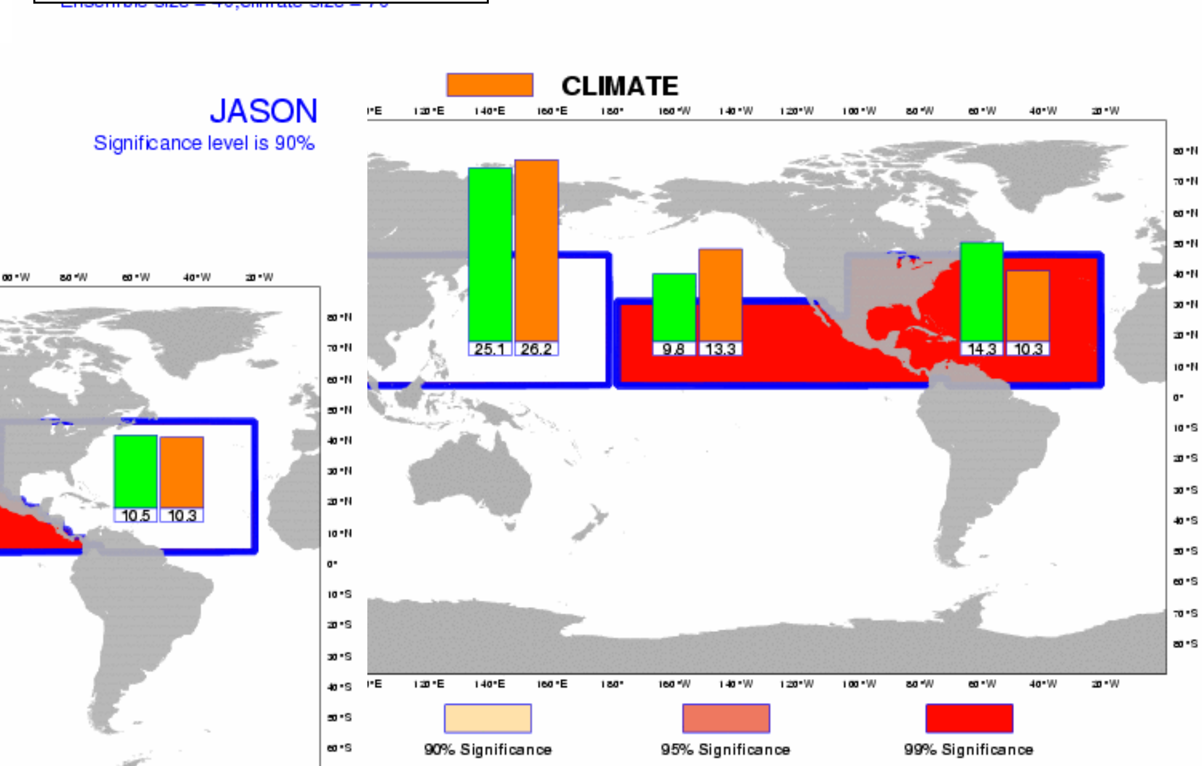




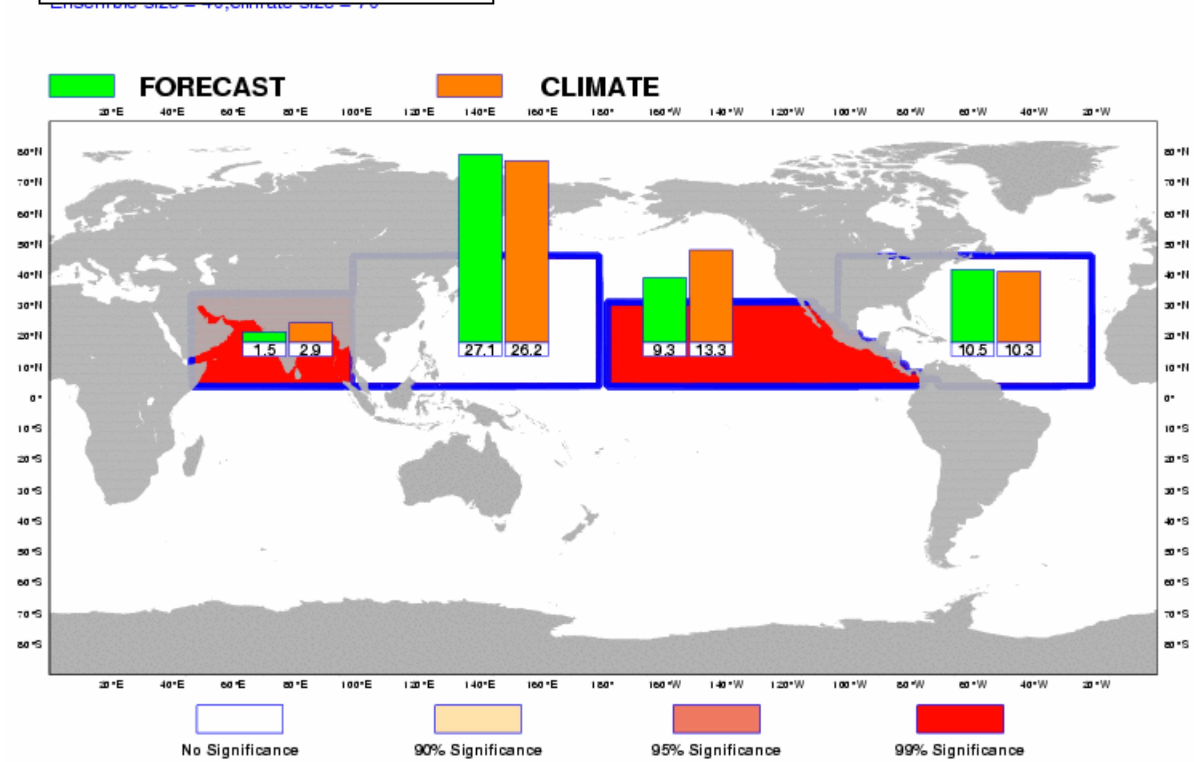
Signal is often present even in the extremes

Seasonal Forecast products: Tropical Storm Frequency

2005



2006



ECMWF

Summary

- We have seen the seasonal forecast components and some of the available products. Many more are available at: http://www.ecmwf.int/products/forecasts/d/charts

- In the next lectures we'll see how these products may be used in practice and what their accuracy is.


Thank you for your attention
STOP

Break