Future perspective of seasonal prediction system developments at ECMWF

ECMWFにおける季節予報システム開発の展望

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European Centre for Medium-Range Weather Forecasts

Outline 概要

1. ECMWF and its forecasting systems: a brief overview

   ECMWFとその予測システム:概要

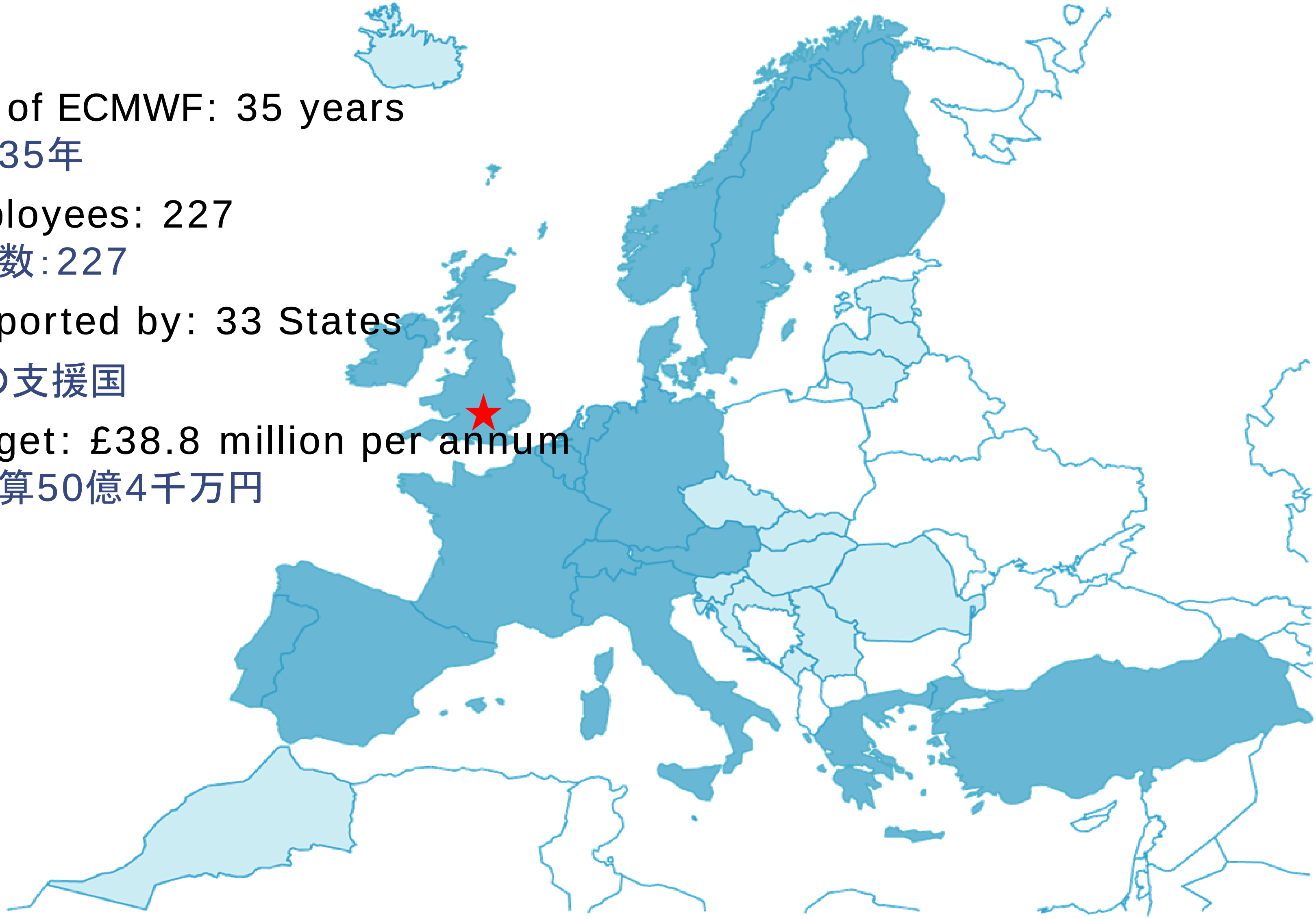
2. Coupled seasonal forecasting at ECMWF: S3 and EUROSIP

   ECMWFの結合季節予報:S3とEUROSIP

3. Future developments (S4) and conclusions

   将来の開発(System 4)と結論

1. ECMWF: few figures (2010)



- Age of ECMWF: 35 years
  設立35年
- Employees: 227
  職員数:227
- Supported by: 33 States
  33の支援国
- Budget: £38.8 million per annum
  年予算50億4千万円

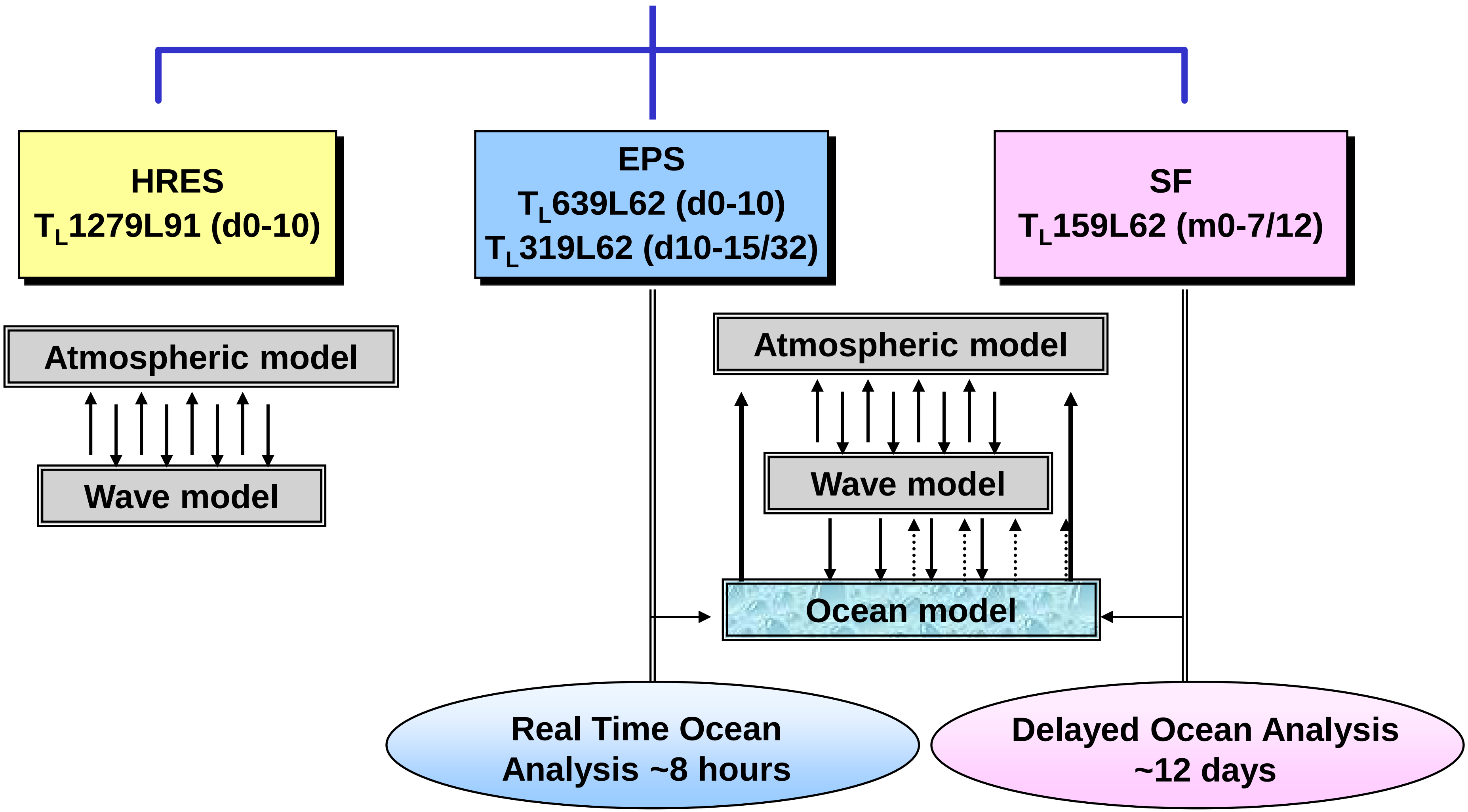
1. ECMWF objectives ECMWFの目的

Three of the key objectives of ECMWF are:

ECMWFの3つの鍵となる目的:

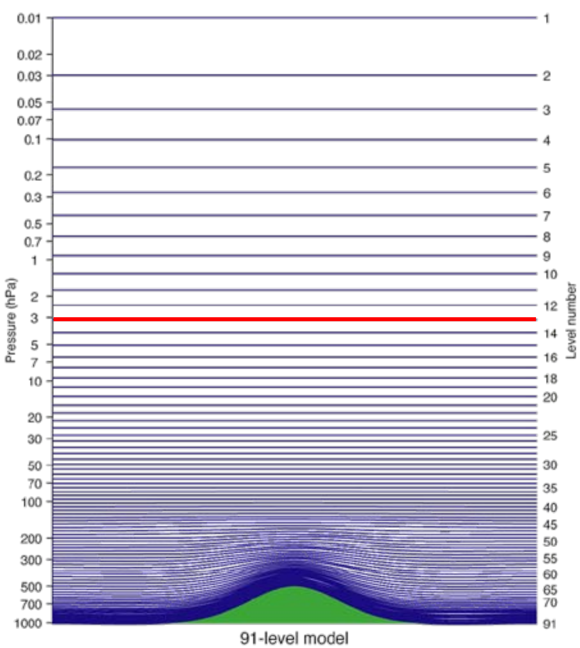
- Operational forecasting up to 15 days ahead (including waves)
  15日先までの現業予報(波浪予報も含む)
- R & D activities in forecast modelling
  予報モデリングにおける研究・現業活動
- Operational forecasts for the coming month and season
  現業1か月・季節予報

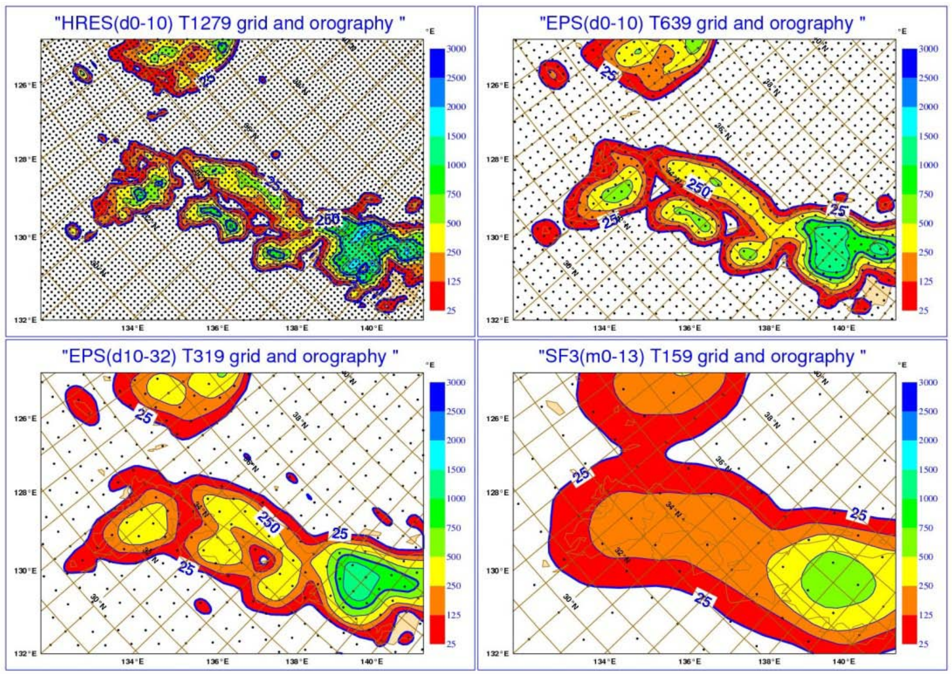
1. Baseline operational systems (2010)
基本となる現業システム(2010年)



1. The ECMWF systems
ECMWFのシステム

	# fcs 数	Hor resolution 水平解像度		Vert lev 鉛直解像度	Fc length 対象期間	Wave 波浪	Ocean 海洋		
HRES/DA 高解像度 データ同化	1	T1279	16 km	91 (<0.01 hPa, 75km)	0-10d	WAM (0.25°, 28km) 波浪モデル	No		
EPS アンサンブル予報	51	T639	32 km	62 (<5 hPa, 35km)	0-10d	WAM (0.5°, 56km)	No		
		T319	64 km		10-15/32d		HOPE	0.3-1.4 deg	L29
S3 季節予報システム	41	T159	125km	62 (<5 hPa, 35km)	0-13m	WAM	HOPE	0.3-1.4 deg	L29





1. Numerical Weather Prediction (NWP) models
数値天気予報システム

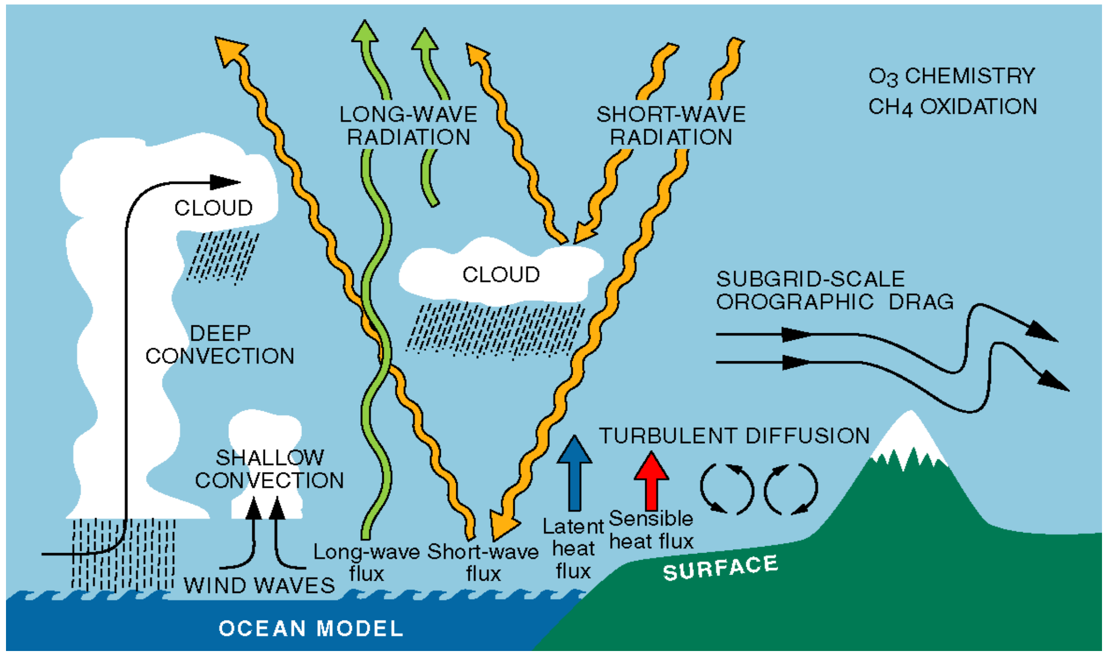
The ECMWF model is based on the fluid dynamics laws of physics that describes how air masses move, heating and cooling processes, the water cycle, the role of radiation, …

The interactions between the atmosphere and the underlying land and ocean are also very important in determining the weather.

The key requisite for skilful weather prediction is a very accurate forecast model.

ECMWF MODEL / ASSIMILATION SYSTEM

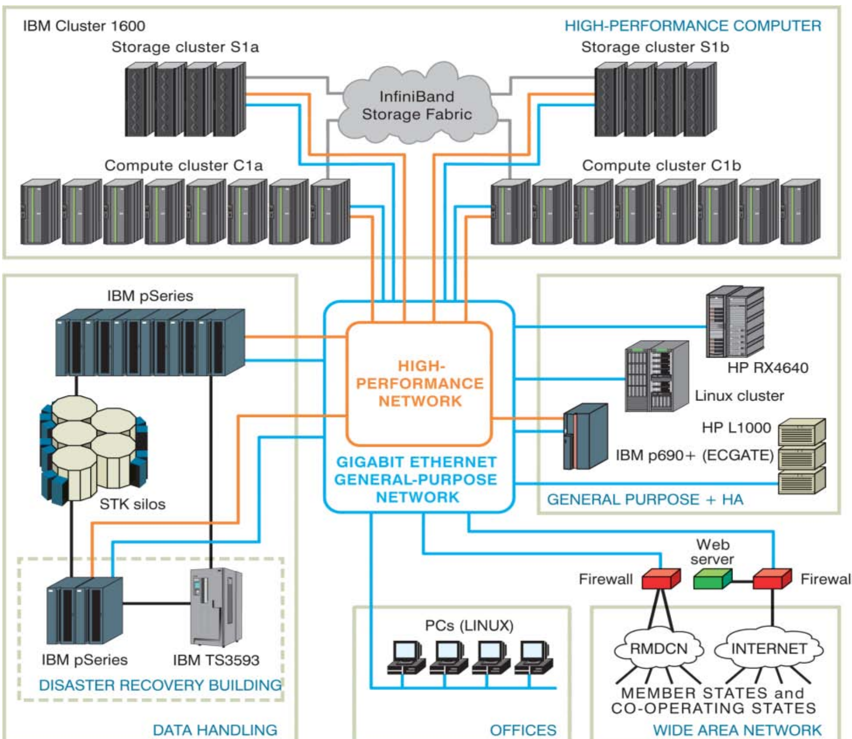
ATMOSPHERE	STRATOSPHERE	DYNAMICS–RADIATION–SIMPLIFIED CHEMISTRY		
	TROPOSPHERE	DYNAMICS–RADIATION–CLOUDS–ENERGY & WATER CYCLE		
OCEAN / LAND		OCEAN	LAND HYDROSPHERE	LAND BIOSPHERE
		OCEAN SURFACE WAVES OCEAN CIRCULATION SIMPLIFIED SEA ICE	SNOW ON LAND SOIL MOISTURE FREEZING	LAND SURFACE PROCESSES SOIL MOISTURE PROCESSES SIMPLIFIED VEGETATION



1. ECMWF comp in '78 (Cray 1A) & '10 (IBM p6+)

ECMWFのスーパーコンピュータ Cray 1A(1978)&IBM p6+(2010)

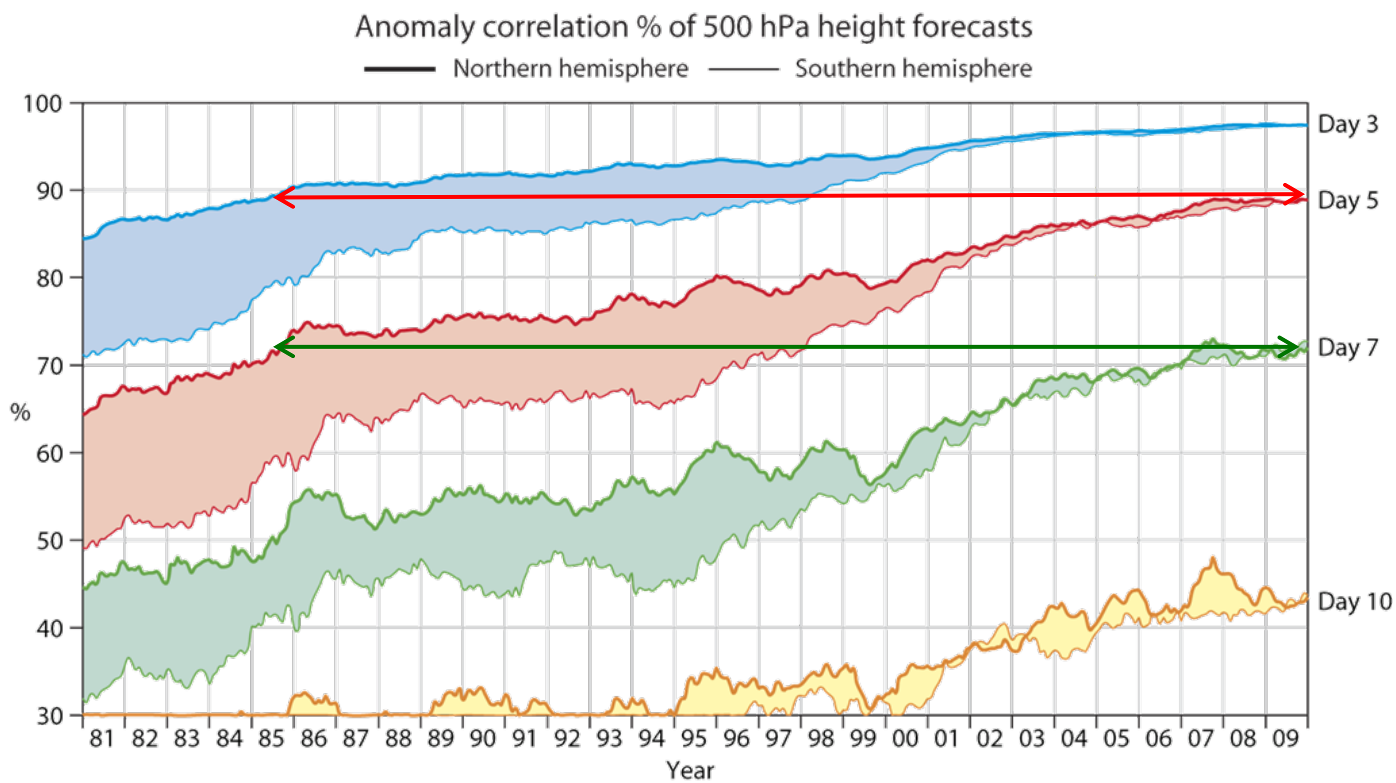
Another key ingredient for skilful weather prediction is computer power, that should be enough to estimate the initial state and to integrate the model equations in a reasonable amount of time.



	1978	2010	Ratio
Specification	Cray 1A	IBM Power6+	
CPU	1	2x8700	~17000
Clock speed (ns)	12.5	0.21	~0.016
Peak perf (flops)	160 M	200 T	~10^6
Sust perf (flops)	50 M	20 T	$0.4 \cdot 10^6$
Disk space (bytes)	2.5 G	1.2 P	$0.5 \cdot 10^6$

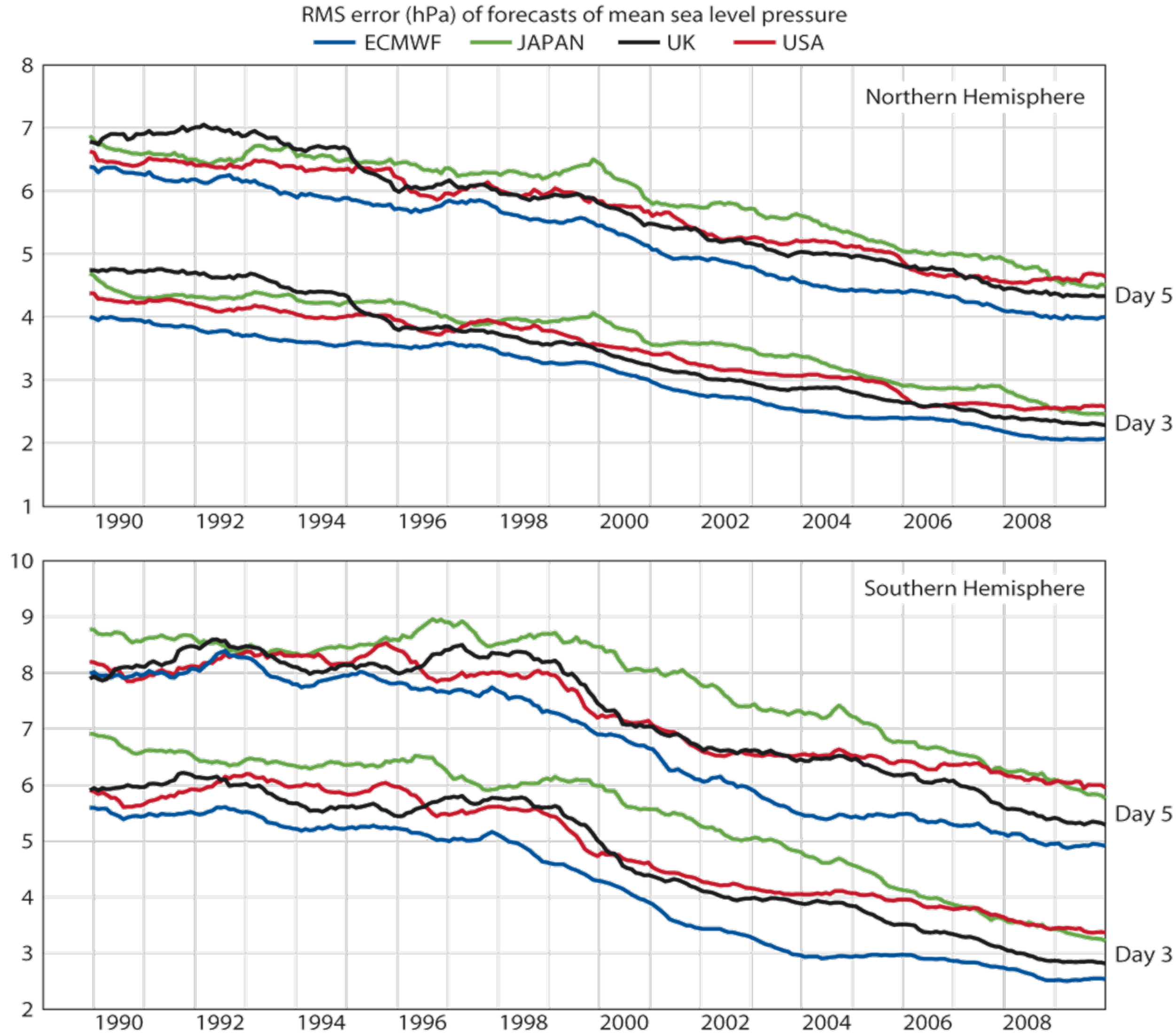
1. HRES performance: Z500 over NH & SH
高解像度予報の精度:北半球・南半球の500hPa高度

The combination of improved data-assimilation and forecasting models, the availability of more/better observations (especially from satellites), and higher computer power have led to increasingly accurate weather forecasts. Today, over NH a day-7 single forecast of the upper-air atmospheric flow has the same accuracy as a day-5 in 1985, and a day-5 as a day-3.



1. HRES performance: ECMWF, UK, US and Japan

高解像度予報の精度(地上気圧): ECMWF、UK、US、日本



1. ACC(Z500) for JJA 2008 over Europe
ヨーロッパ域の2008年6-8月の500hPa高度 偏差相関係数

Time series curves
500hPa Geopotential
Anomaly correlation forecast
Europe Lat 35.0 to 75.0 Lon -12.5 to 42.5
T+120

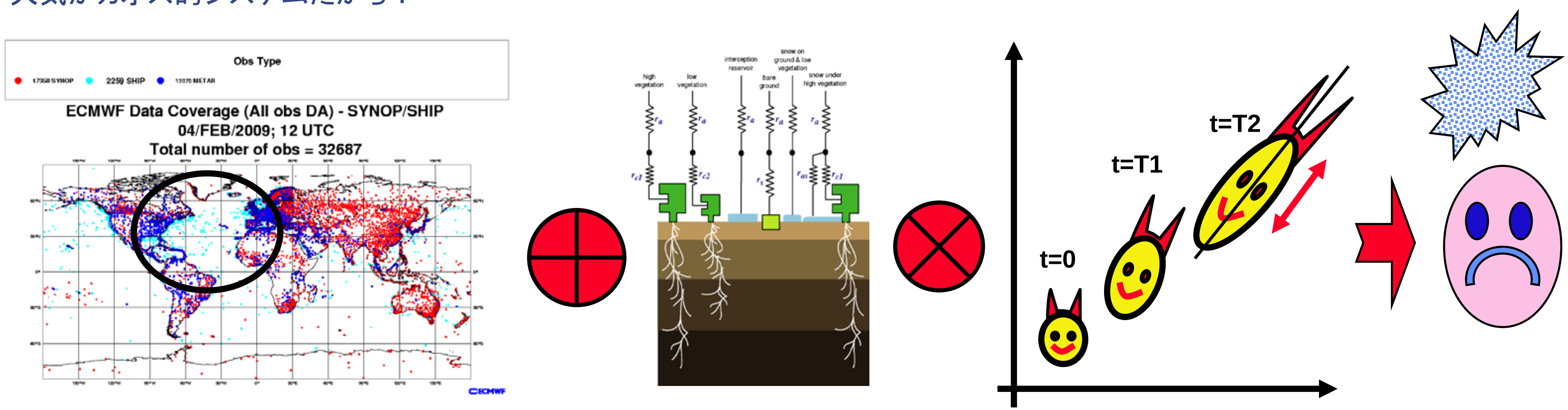
1. Why do forecasts fail?
なぜ予報が外れるのか？

Forecasts can fail because:

- The initial conditions are not accurate enough, e.g. due to poor coverage and/or observation errors, or errors in the assimilation (initial uncertainties).初期値の誤差
- The model used to assimilate the data and to make the forecast describe only in an approximate way the true atmospheric phenomena (model uncertainties). モデルの誤差
- Boundary conditions (albedo, snow cover, vegetation, ..) is poorly simulated

As a further complication, the atmosphere is a chaotic system!

大気がカオス的システムだから！



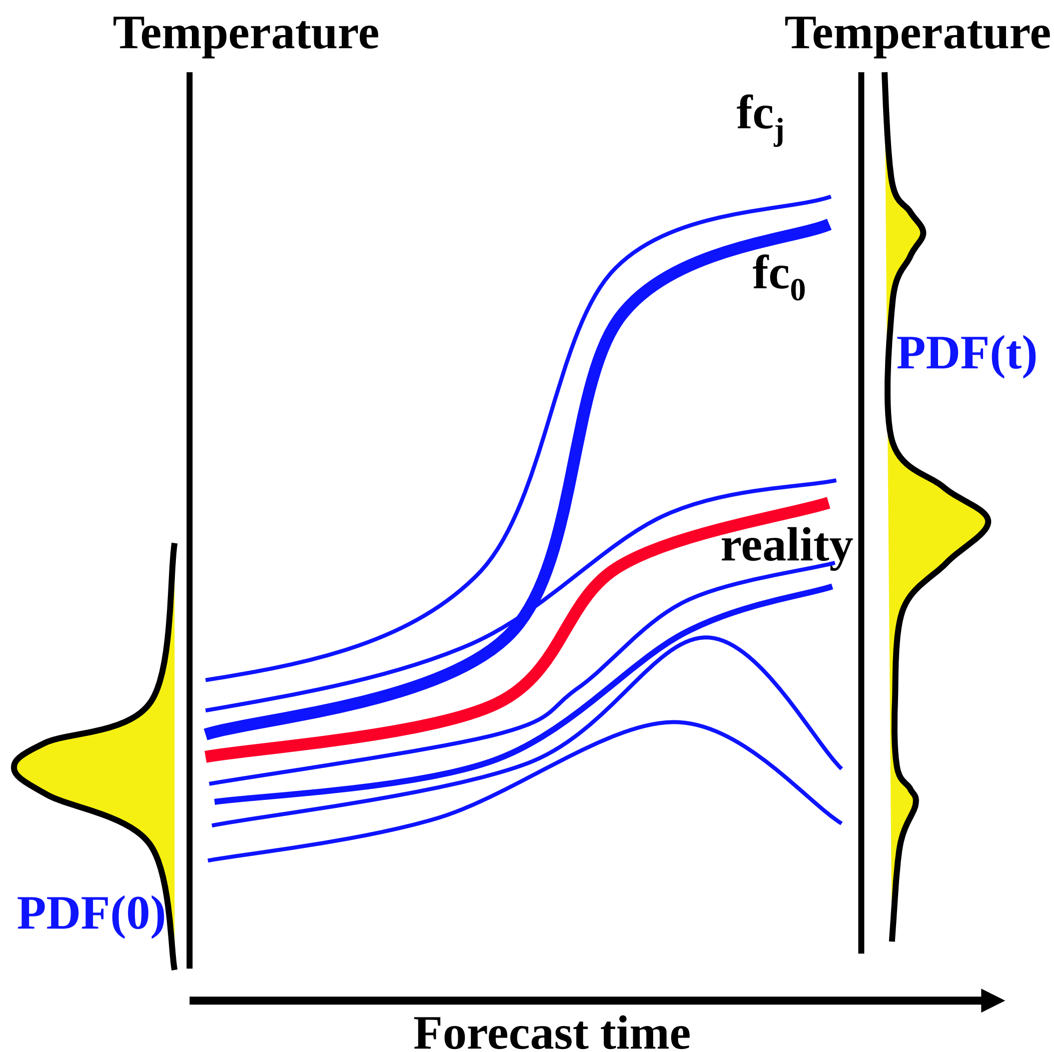
1. Ensemble Prediction Systems (EPS)
アンサンブル予報システム (EPS)

A complete description of weather prediction can be stated in terms of an appropriate probability density function (PDF).

Ensemble prediction based on a finite number of deterministic integration appears to be the only feasible method to predict the PDF beyond the range of linear growth.

Ensemble prediction can be considered as the practical application of chaos theory to weather prediction.

Ensemble methods have been used to extend the forecast range from days to weeks, months and seasons.

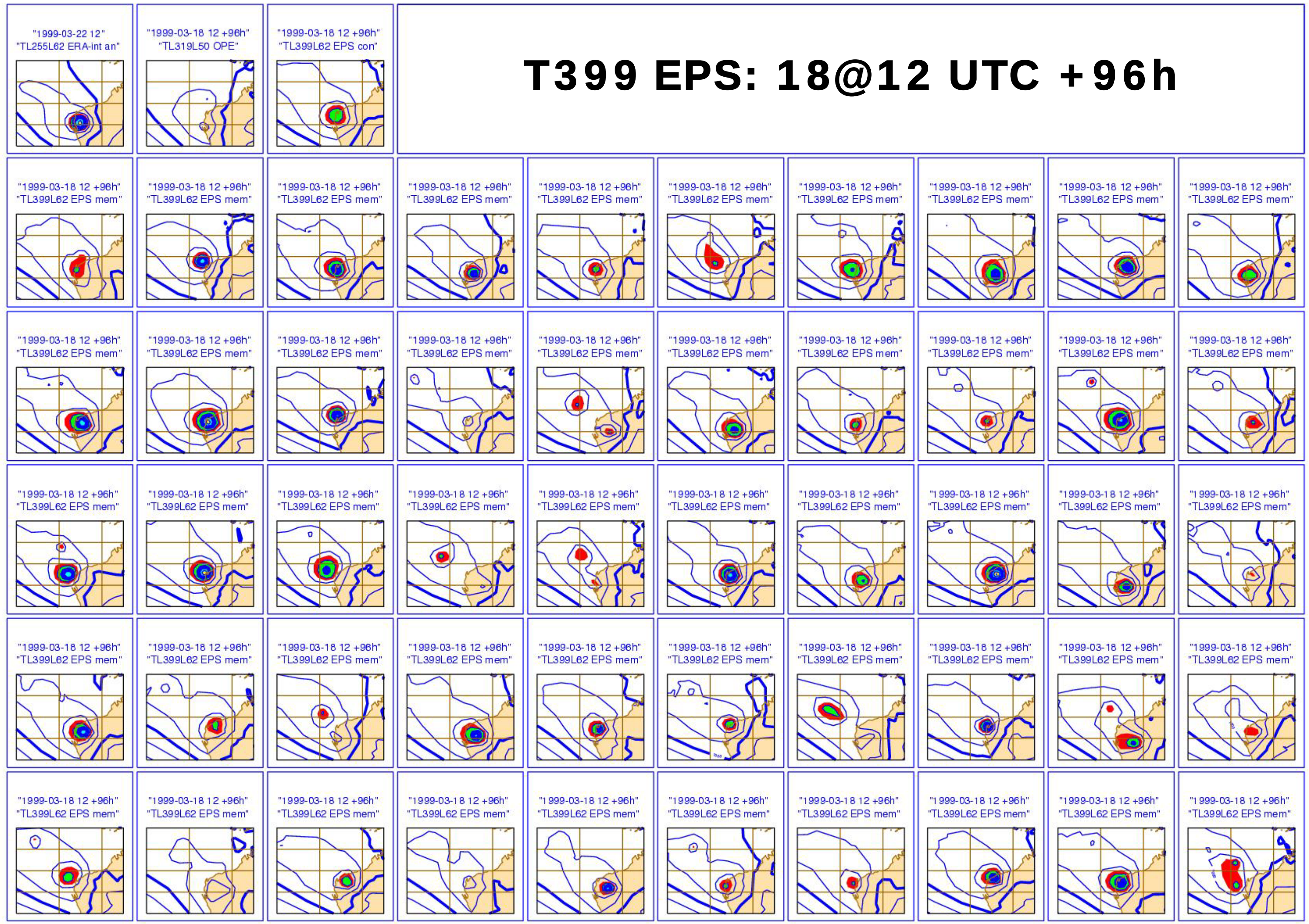


1. EPS fc of TC Vance: T399 EPS, 18@12+96h

熱帯サイクロン Vance のT399 EPS予測1999年3月18日 96時間予報

An example of an ensemble of forecasts from the ECMWF EPS, which is based on 51 forecasts designed to simulate initial and model uncertainties.

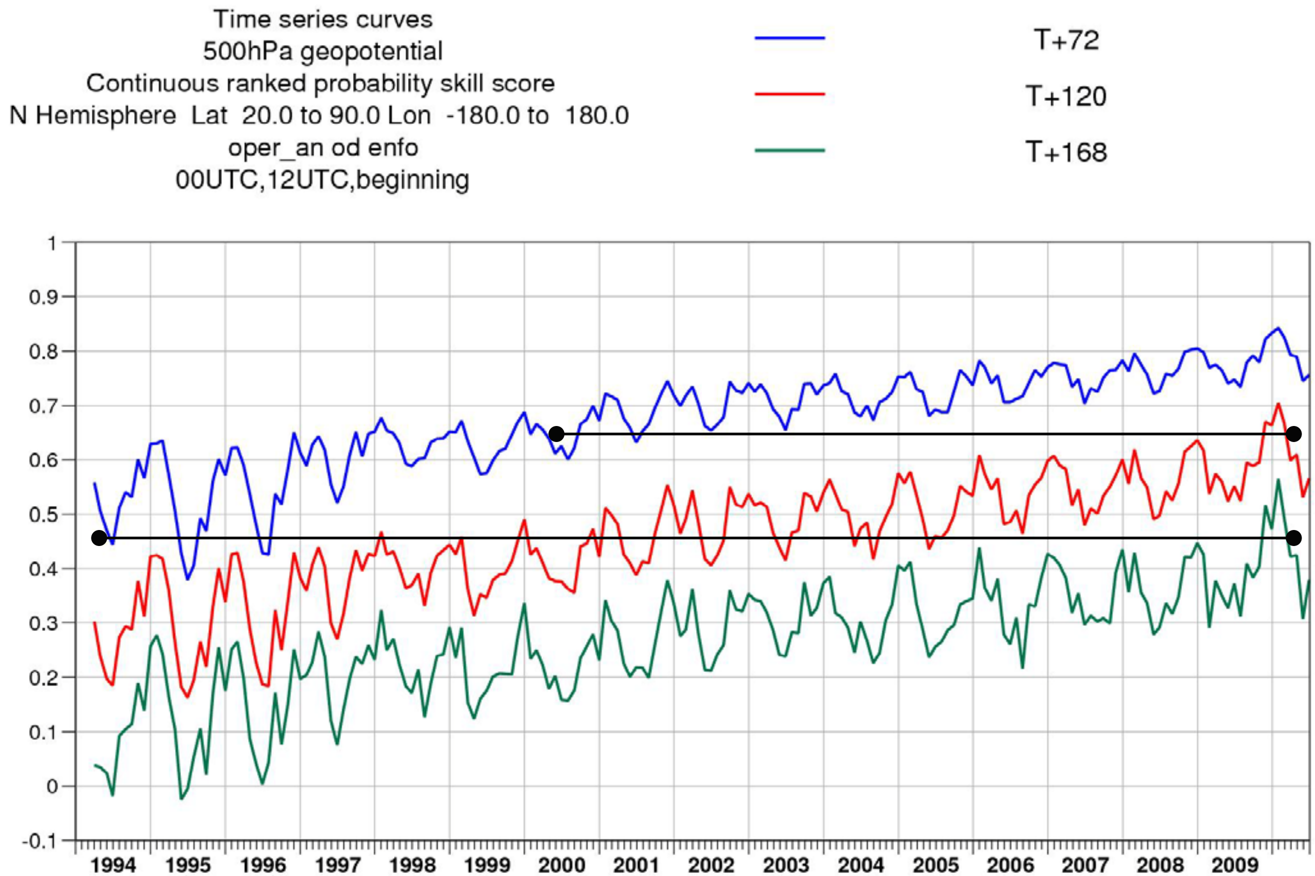
This plot shows the EPS t+96h fcs of TC Vance making landfall in Australia on 22/03/99.



1. EPS performance: T850 over NH
EPSの予測精度 北半球850hPa気温

The performance of the EPS has been improving continuously for upper level fields, as seen by looking at the CRPSS for the t+72h, t+120h and t+168h probabilistic prediction of T850 over NH(verified against analyses).

Results indicate predictability gains of ~ 2 days/decade.



(Thanks to Martin Janousek)

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   将来の開発（System 4）と結論

2. The rationale behind seasonal prediction
季節予報の理論的根拠

- Long term predictions are possible to some degree thanks to a number of components that show variations on long time scales and, to a certain extent, are predictable. The most important of these components is the ENSO (El Nino Southern Oscillation) cycle which refers to the coherent, large-scale fluctuation of ocean temperatures, rainfall, atmospheric circulation, vertical motion and air pressure across the tropical Pacific.

- ENSO's fluctuations are quite vast, with the changes in sea-surface temperatures (SSTs) often affecting not just the whole width of the Pacific but the other ocean basins too, and the changes in tropical rainfall and winds spanning a distance of more than one-half the circumference of the earth. The ENSO cycle is the largest known source of year-to-year climate variability.

- Changes in Pacific sea surface temperature (SST) are not the only cause of predictable changes in the weather patterns. There are other causes of seasonal climate variability.

2. The rationale behind seasonal prediction
季節予報の理論的根拠

- Unusually warm or cold sea surface temperatures in the tropical Atlantic or Indian ocean can cause major shifts in seasonal climate in nearby continents. Other factors that may influence seasonal climate are snow cover and soil wetness. When snow cover is above average for a given season and region, it has a greater cooling influence on the air than usual.

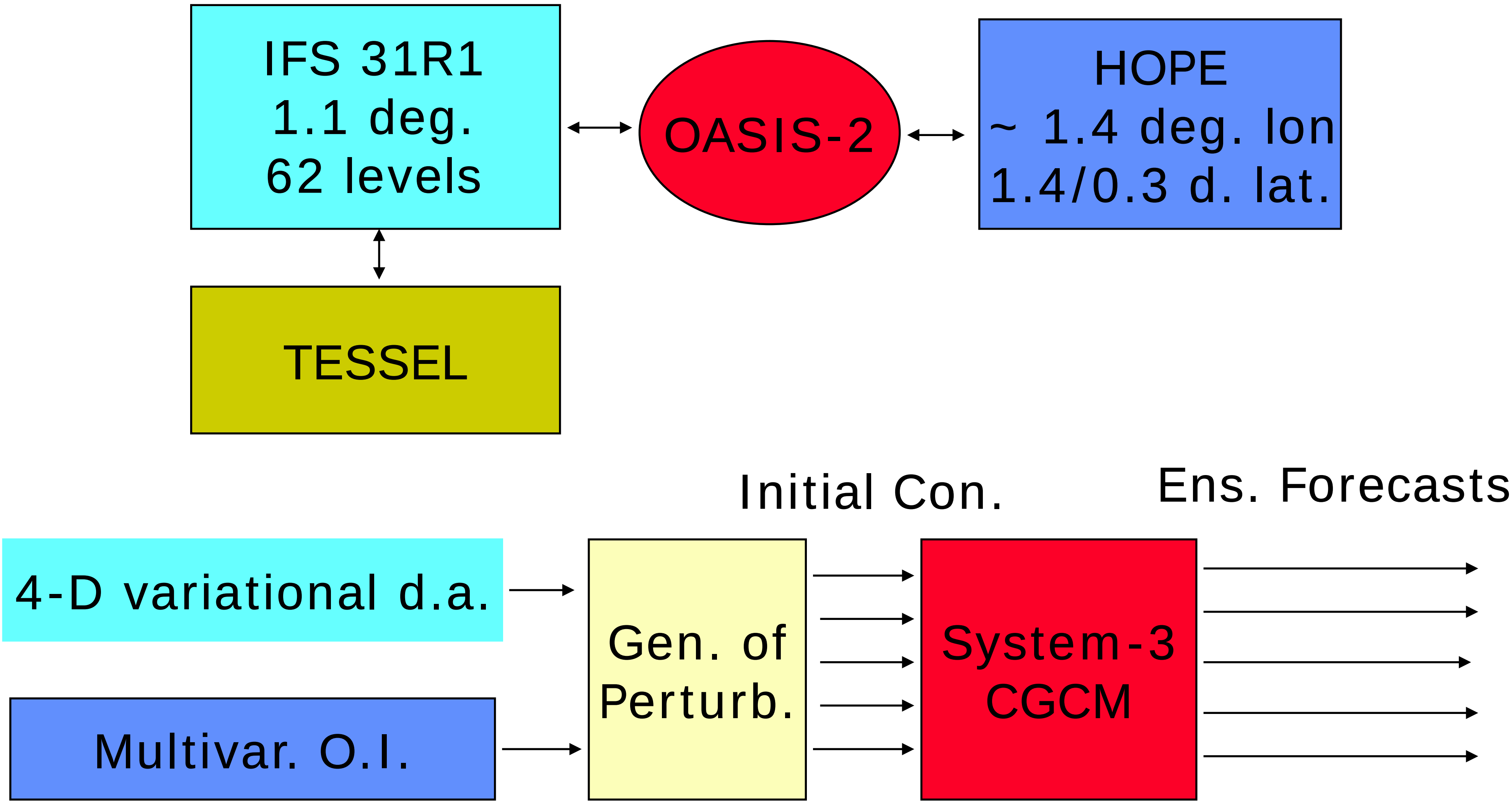
- Soil wetness, which comes into play most strongly during warm seasons, also has a cooling influence. All these factors affecting the atmospheric circulation constitute the basis of long-term predictions.

- These are some of the reasons why long-range predictions have been developed.

- **Ensemble methods have been applied to build seasonal prediction systems. At ECMWF, seasonal forecasts have been produced since 1998.**

2. ECMWF operational system S3 (2006-todate)

ECMWF 現業システム System 3 (2006-現在)



2. S3 Ocean multi-variate O.I. data-assimilation System 3 多変量 最適内挿法 データ同化

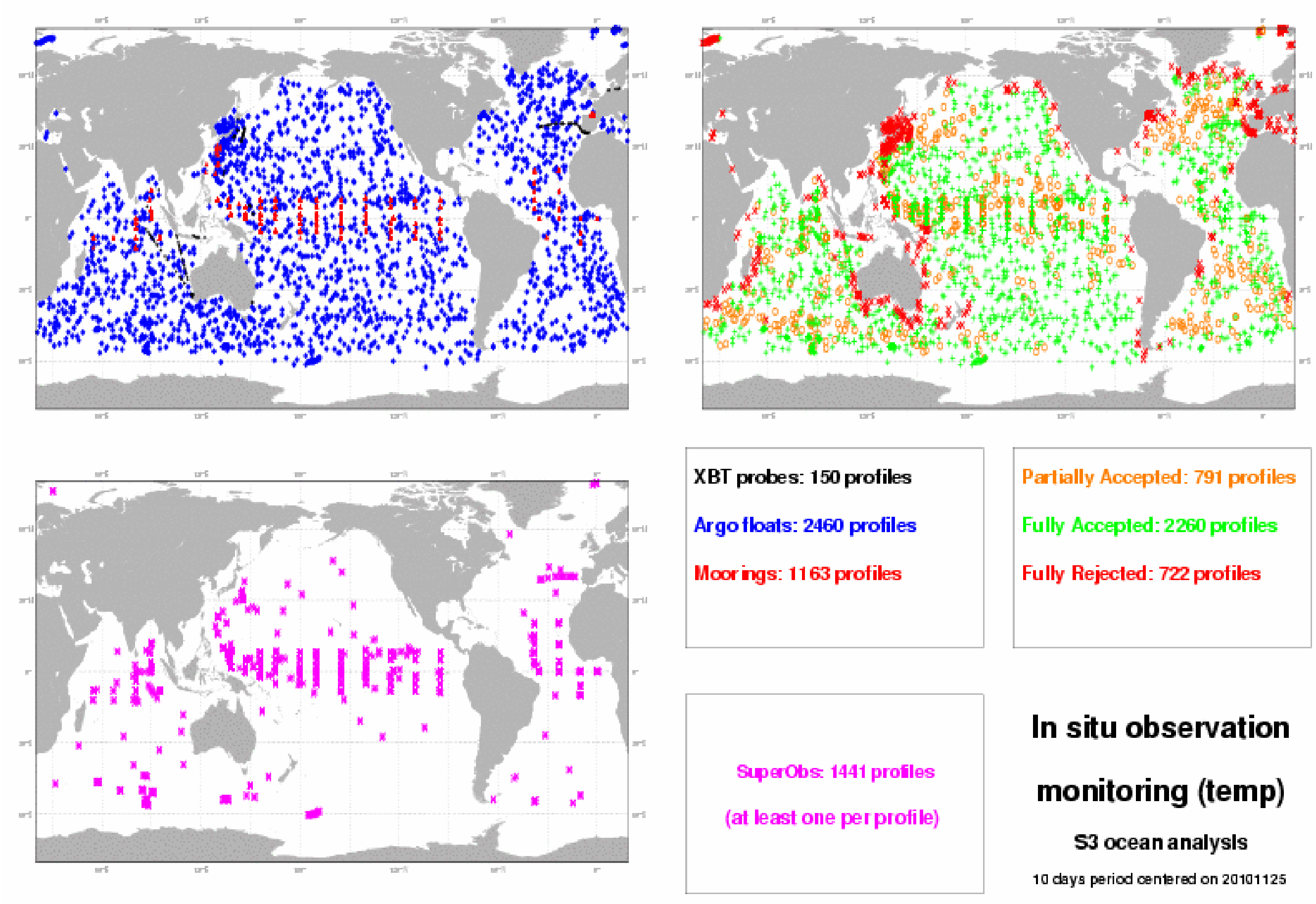
- Ocean ICs are the main source of predictability at seasonal time scales. The correct initialization of the upper ocean thermal structure is considered instrumental in the prediction of the tropical SST at seasonal timescales with dynamical models. At the monthly time scales, the prediction of phenomena such as the MJO requires the correct representation of the ocean-atmosphere interactions.

- A historical ocean reanalysis is required to provide initial conditions for the calibration of the seasonal forecasts. The a-posteriori calibration of model output requires an estimate of the model climatology, which is obtained by performing a series of coupled hindcasts during some historical period (typically 10-20 years, 25y 11m in the operational S3 hindcasts).

- An ensemble of 5 ocean analyses is performed to estimate the uncertainty in the ocean initial conditions. The ensemble of ocean initial conditions contributes to the creation of the ensemble of forecasts for the probabilistic predictions at monthly and seasonal ranges.

2. S3 Ocean ICs: real-time analysis
System 3 海洋初期値: リアルタイム解析

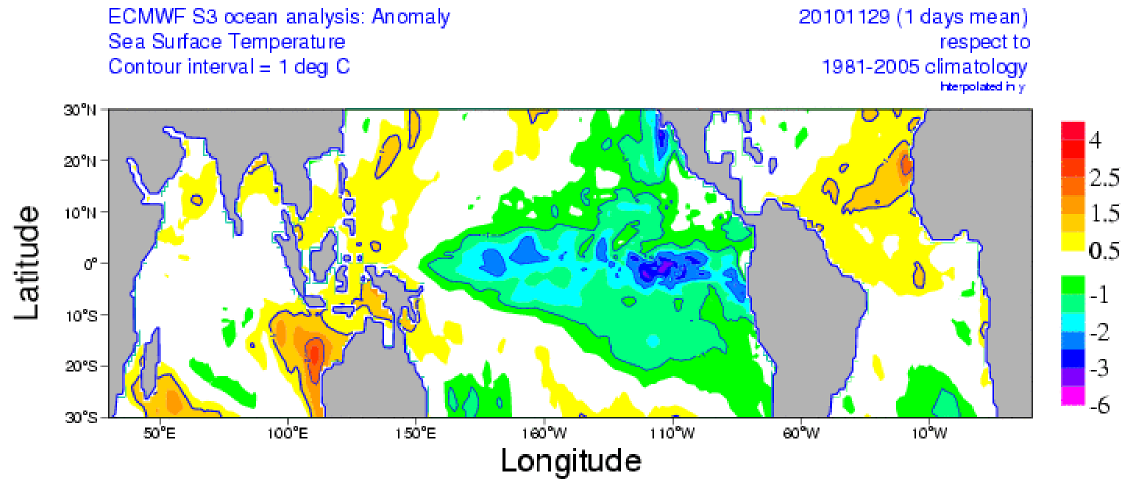
The ocean analysis is performed every 10 days. All obs within a centered 10-days window are gathered and quality controlled. In the S3 HOPE-OI system, in addition to subsurface temperature, the scheme assimilates altimeter derived sea-level anomalies and salinity data.

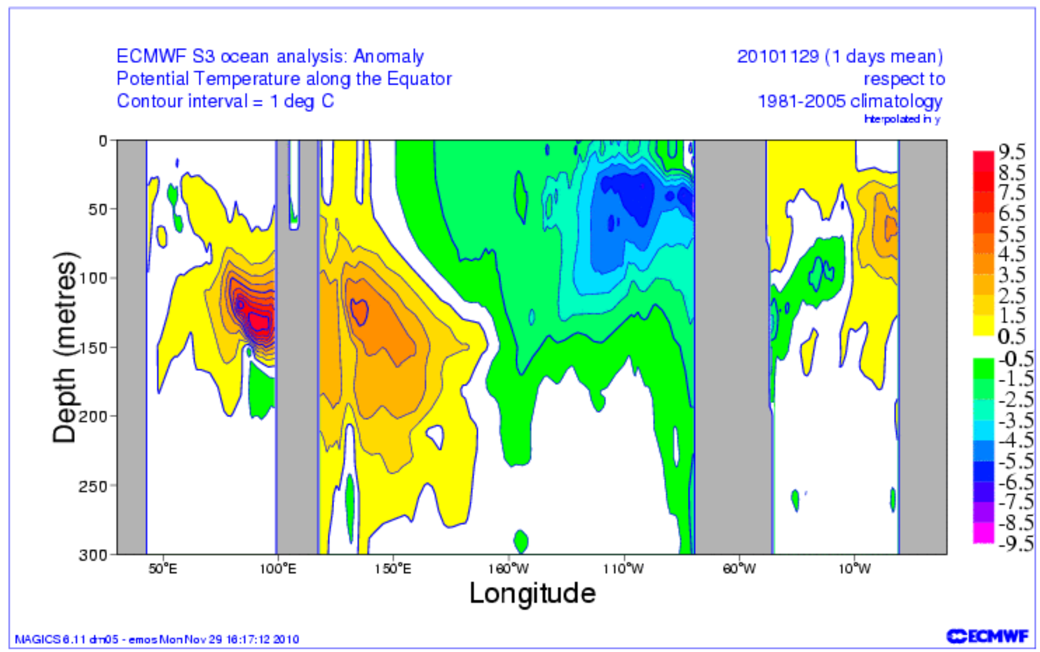


2. S3 Ocean real-time analysis
System 3 海洋リアルタイム解析

Every day, a real-time ocean analysis is produced to initialize the monthly forecasts.

To avoid degradation of the real-time product, the analysis always starts from the most recent Behind Real Time (BRT) analysis and is then brought forward to real time every day.



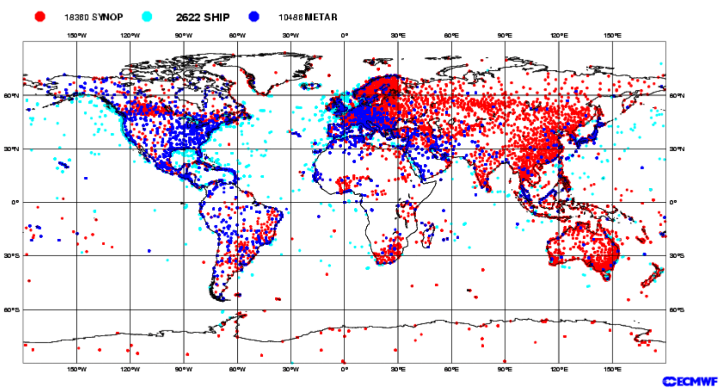


2. The ocean & atmosphere observation systems

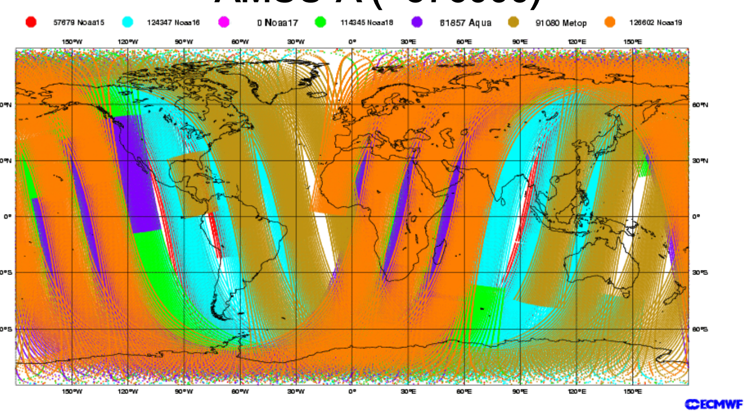
海洋と大気観測システム

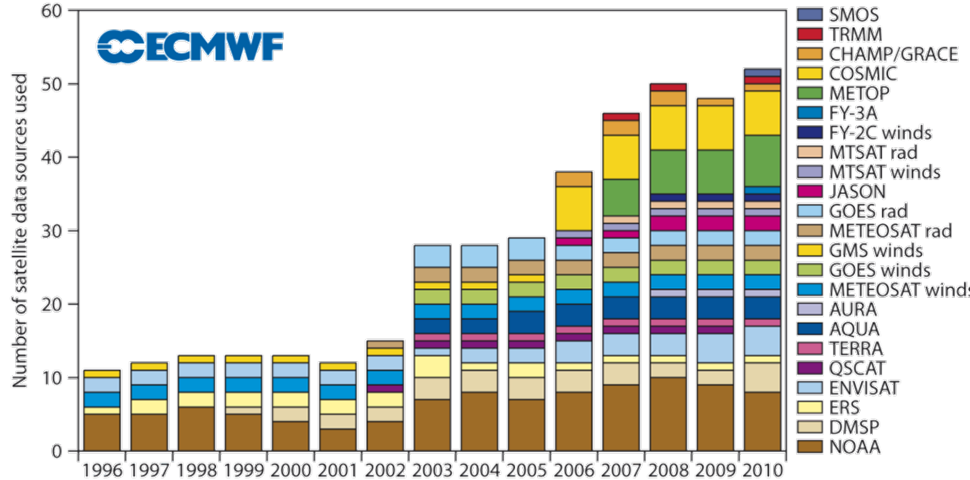
It is interesting to contrast the ocean and atmosphere observing systems. Everyday, ECMWF receives ~ 5k obs of the ocean state and ~100M atmospheric obs (~90% from sat). The atmospheric 12h 4D-Var DA system uses ~10% of these data (~9M obs) to compute the analysis.

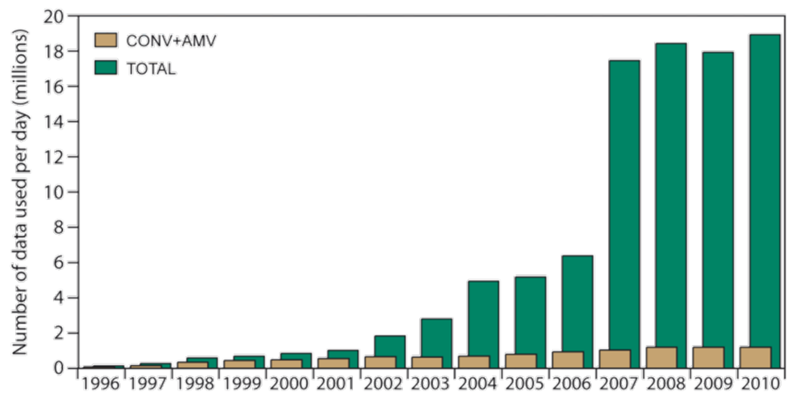
Synop/ship (~31000)



AMSU-A (~576000)



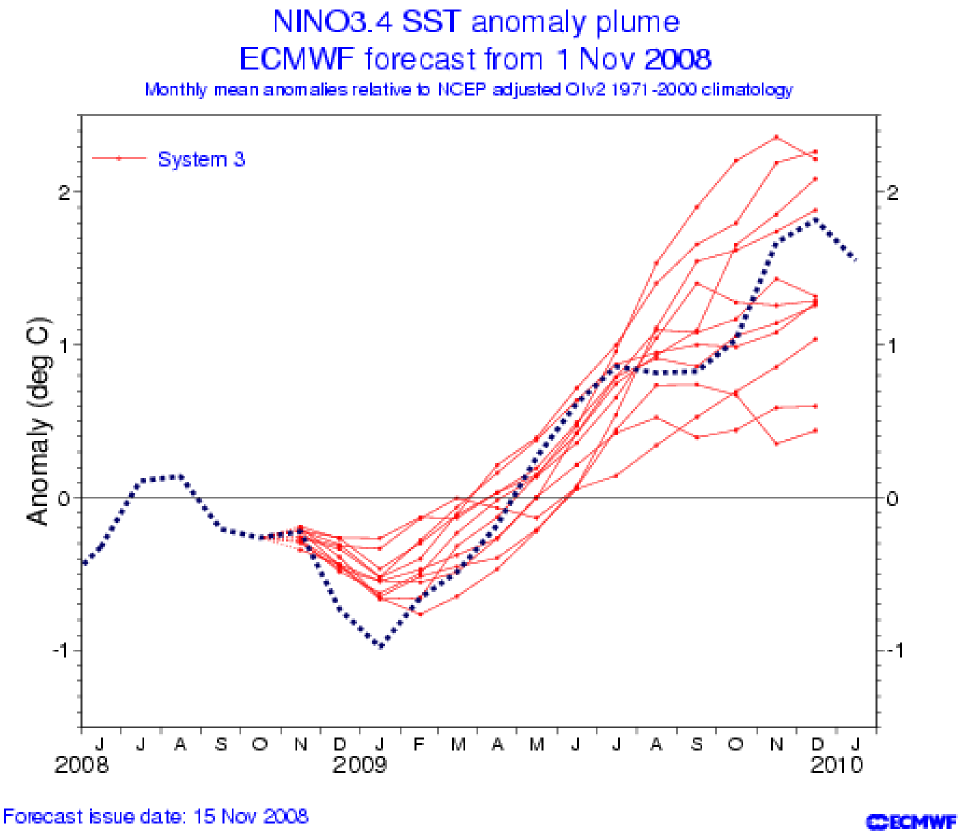


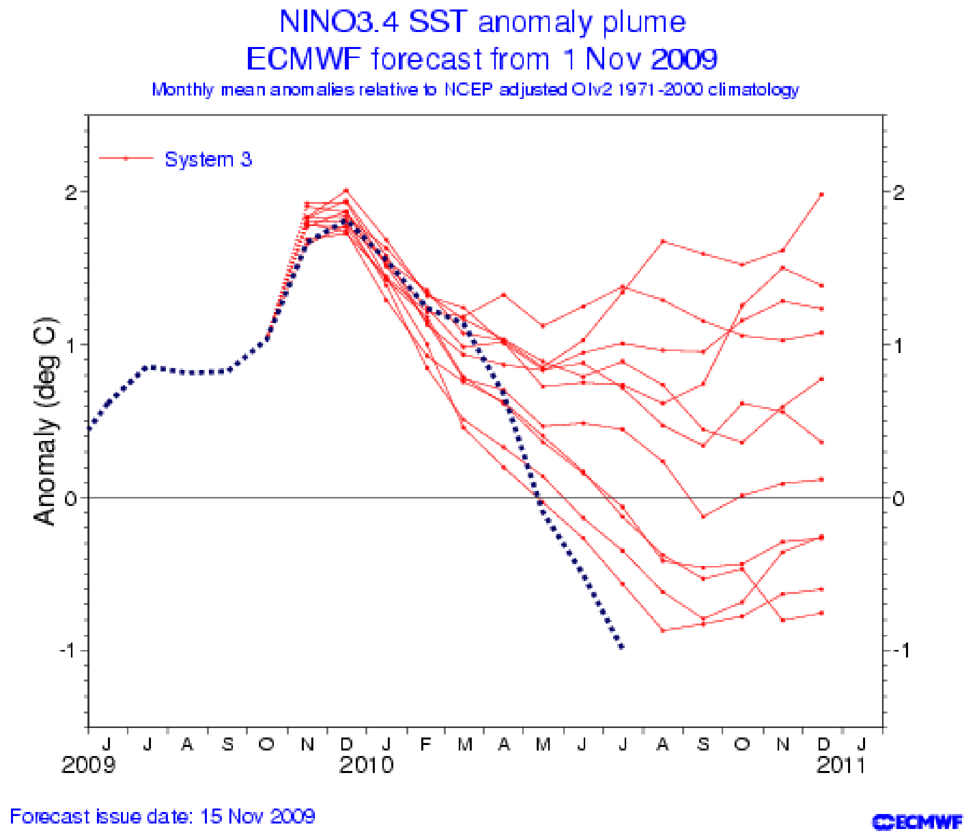


2. 1-year ENSO outlook with S3: 2009-2010

System 3 による 1年間のENSO見通し: 2009-2010

The tropics is the area where seasonal predictability is higher, controlled mainly by ENSO, a coupled ocean-atmosphere phenomenon centred over the tropical Pacific. The ECMWF S3 13m integrations (generated every quarter, based on an 11-member ensemble) gave very good predictions of the most recent warming conditions of 2009.

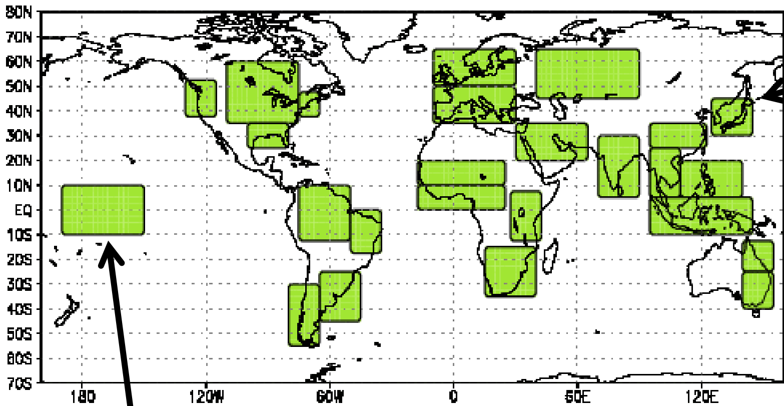




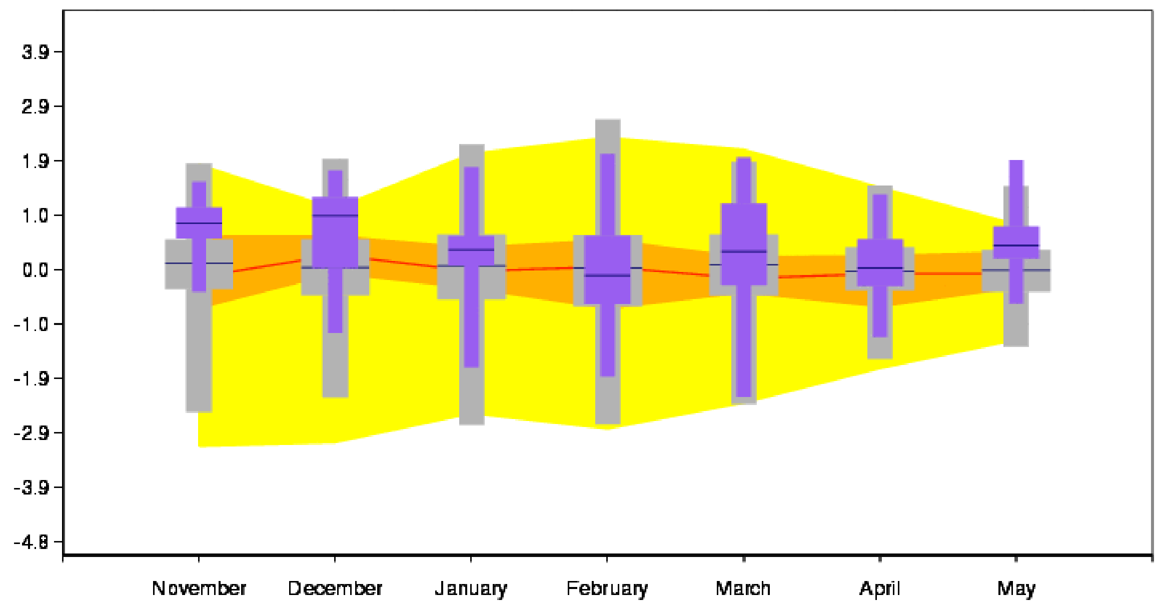
2. S3 2mT climagram forecasts
System 3 2m気温 climagram 予報

One S3 product is the 2mT climagram (top-right), which shows the distribution of the S3 forecast (purple), the model climate (grey) and the analysis. A red dot indicates the observed anomaly.

Japan / Korea



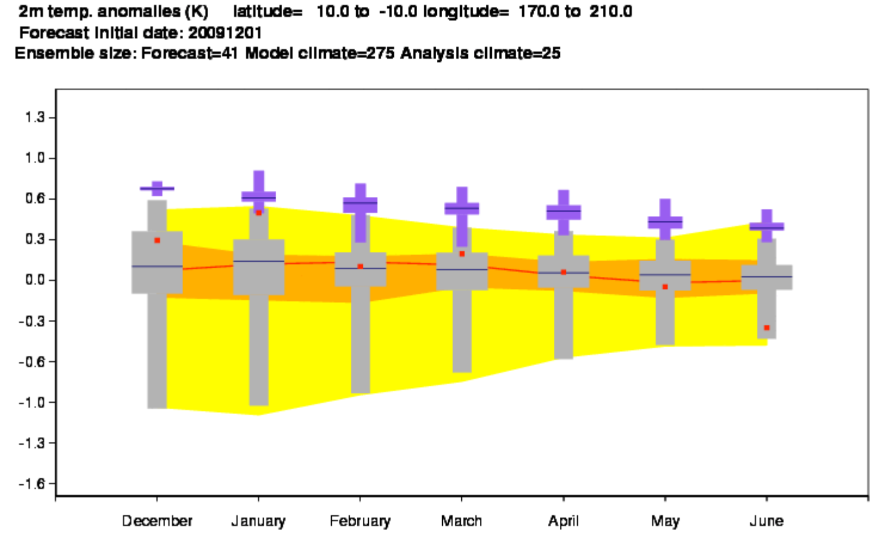
Central tropical Pacific

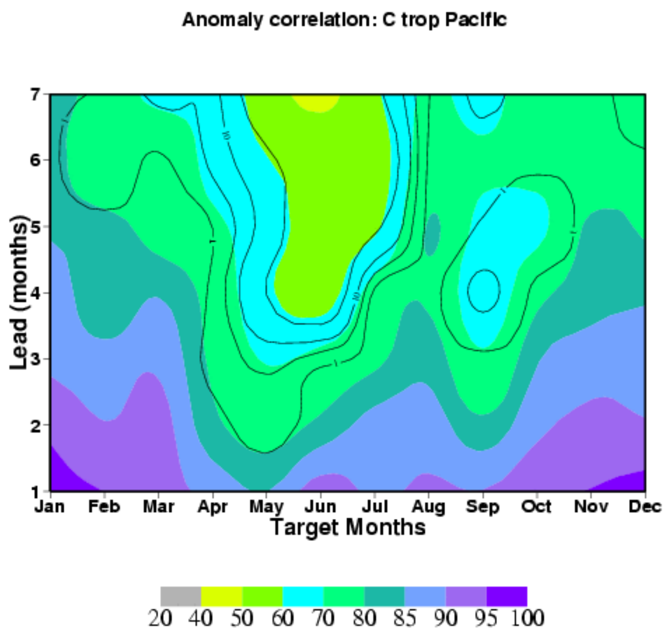


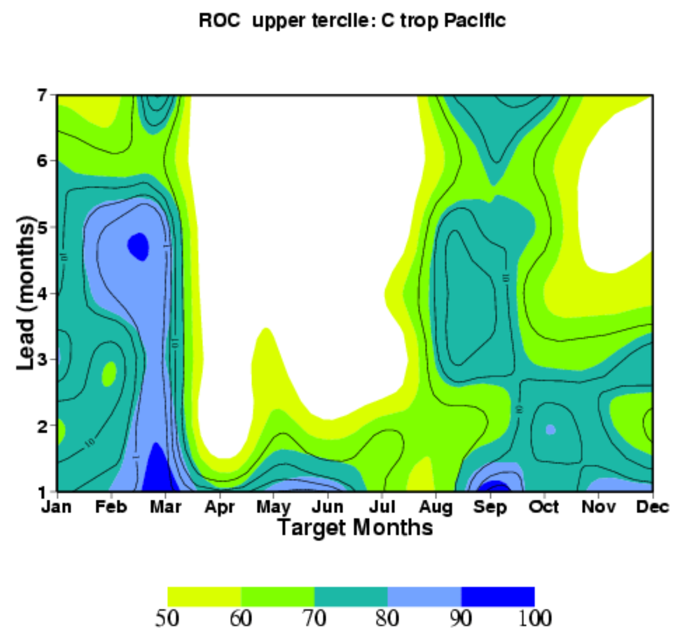
2. S3 2mT climagram over central-tropical Pacific
熱帯太平洋中部のSystem3 2m気温 climagram

One S3 product is the 2mT climagram (top-right), which shows the distribution of the S3 forecast (purple), the model climate (grey) and the analysis. A red dot indicates the observed anomaly.

The lower plots show the ACC (left) of the ensemble-mean forecast and the ROCA of the PR(2mT in upper tercile).







2. S3 2mT climagram over Japan / Korea
日本 / 韓国域の System 3 2m気温 climagram

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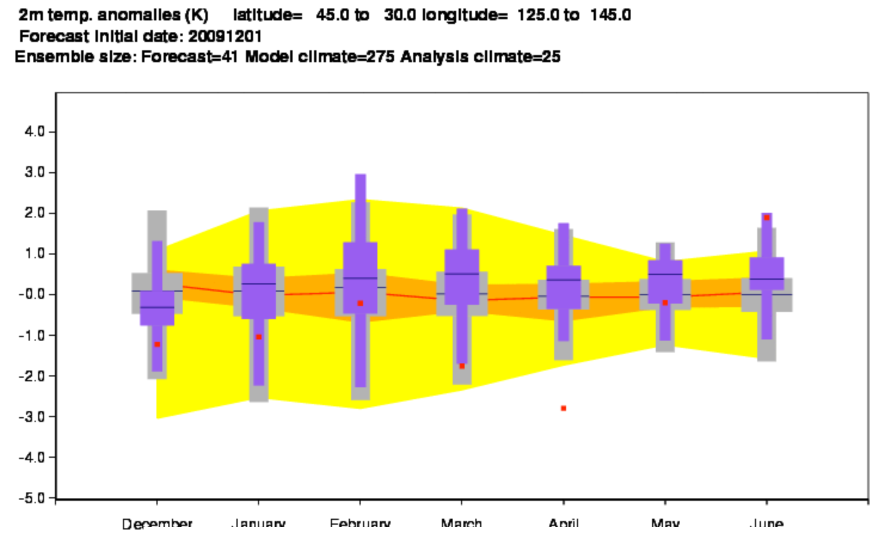
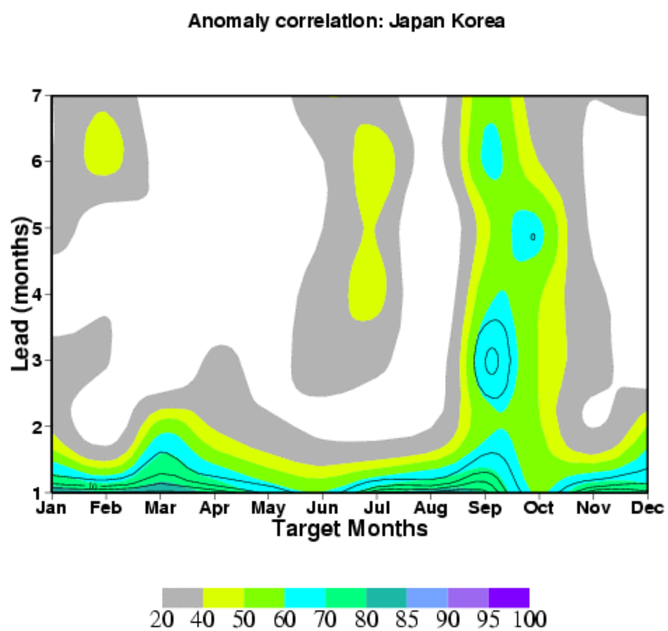
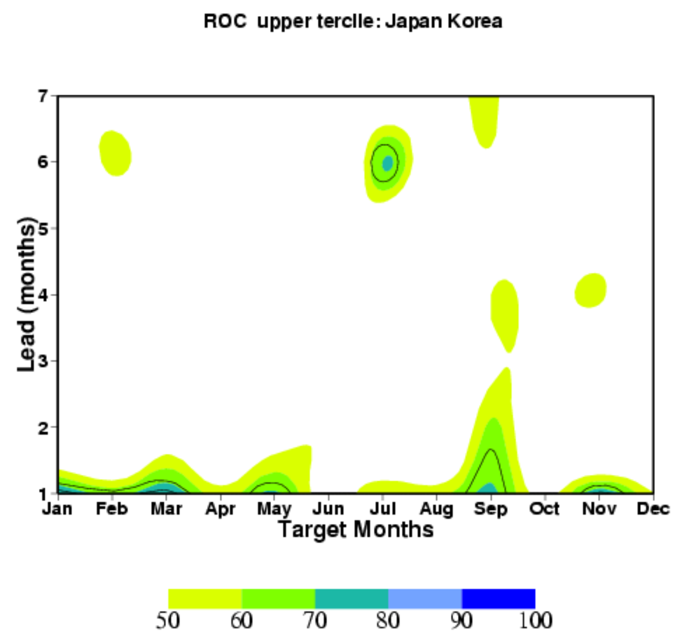


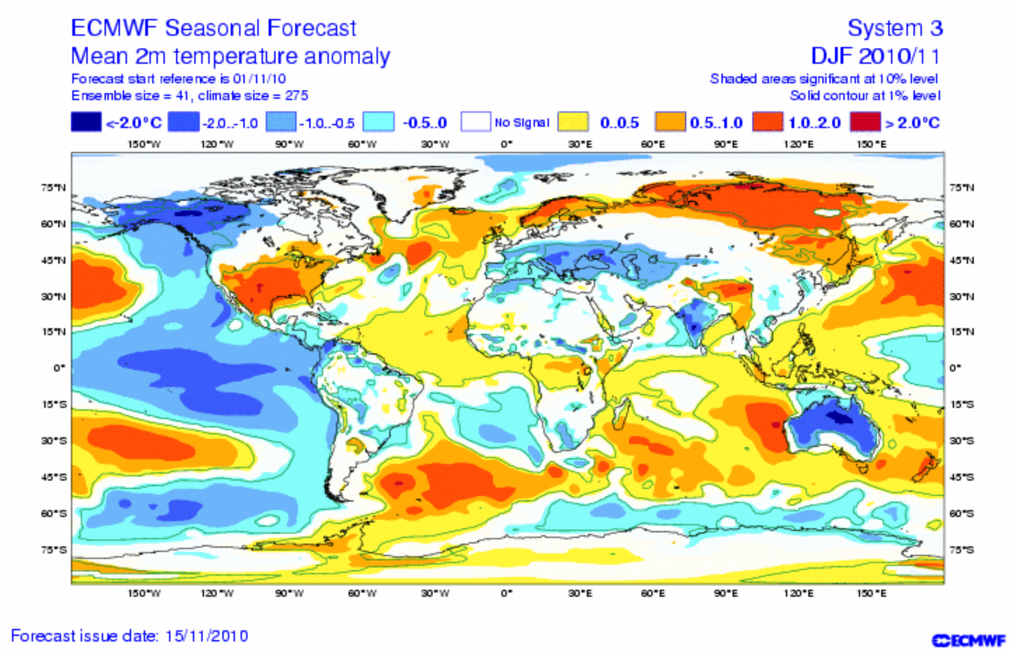


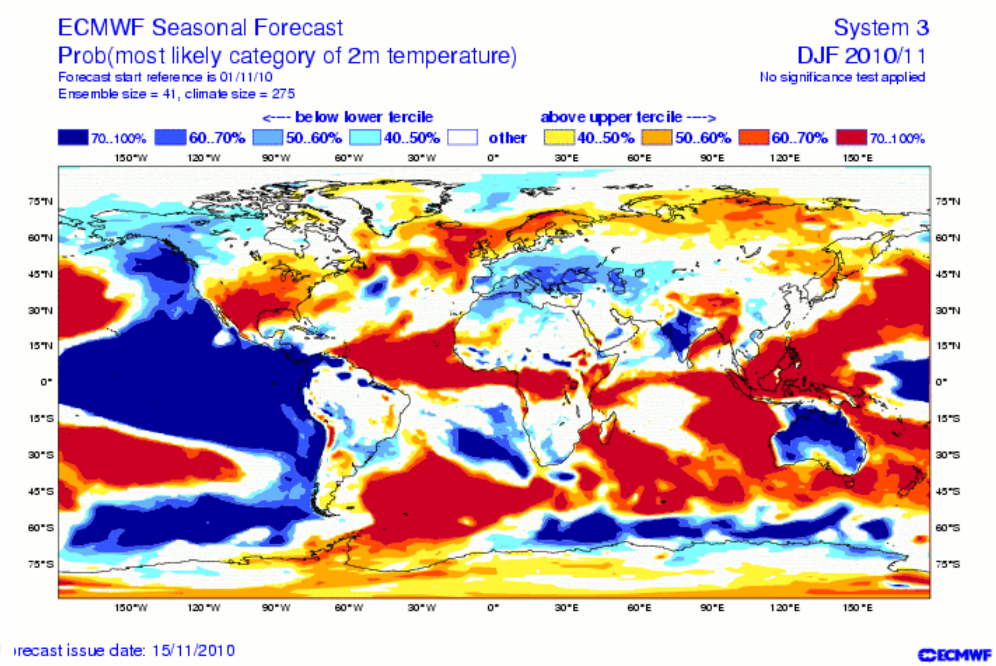


2. S3 2mT-anomaly forecasts: 1 Nov ‘10 > DJF

System 3 2m気温偏差予報:2010年 11月1日初期値 12月～2月

Two examples of S3 forecast products: ensemble-mean (left) and probabilistic forecasts (right) of 2mT anomalies started on 1 Nov 2010 and valid for D10-JF11.



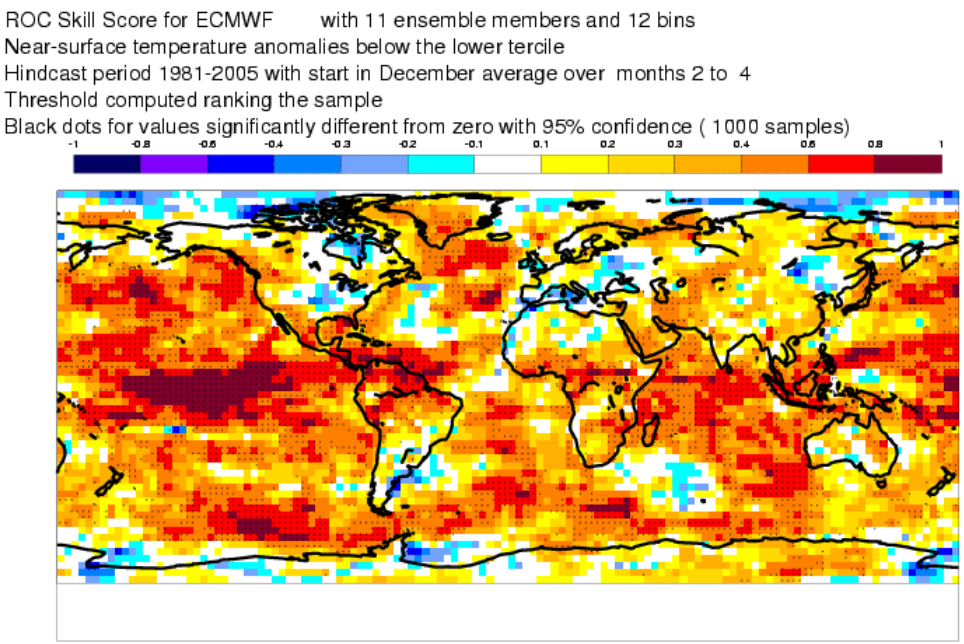


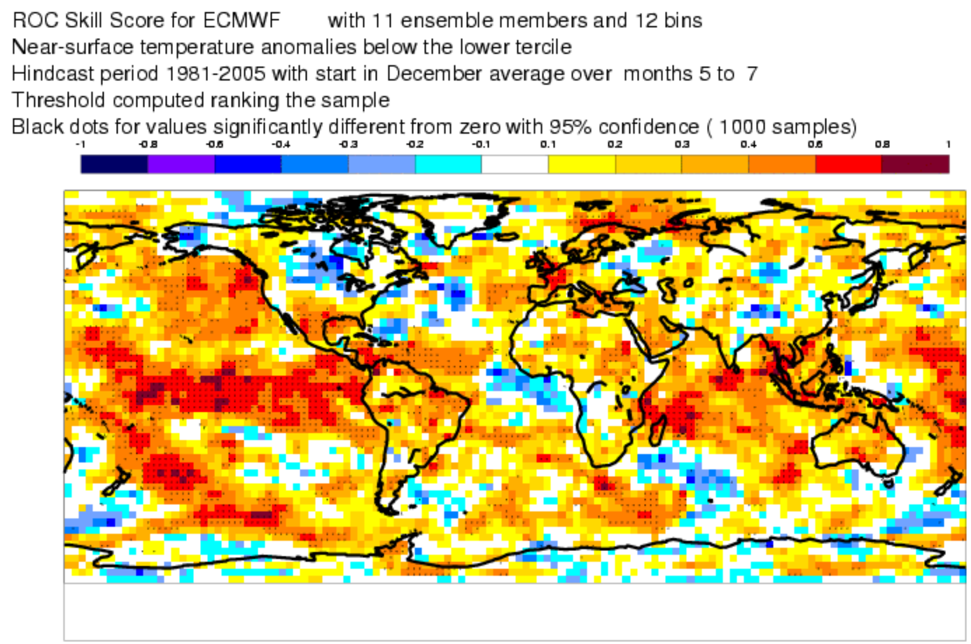
2. S3 2mT-anomaly fcs from 1 Dec: ACC

System 3 2m気温偏差予報の偏差相関係数(12月1日初期値)

These plots show a measure of the accuracy of seasonal probabilistic forecasts, the area under the Relative Operating Characteristics (ROCA) of the probabilistic forecasts of the 2mT anomaly being below the lower tercile forecasts with 1 Dec starting date. The ROCA has been evaluated considering 25-years (1985-2005) 11-member hindcasts.

The left panel shows the ROCA of the 2-4m average forecast, and the right panel the ROCA of the 5-7m average forecast.

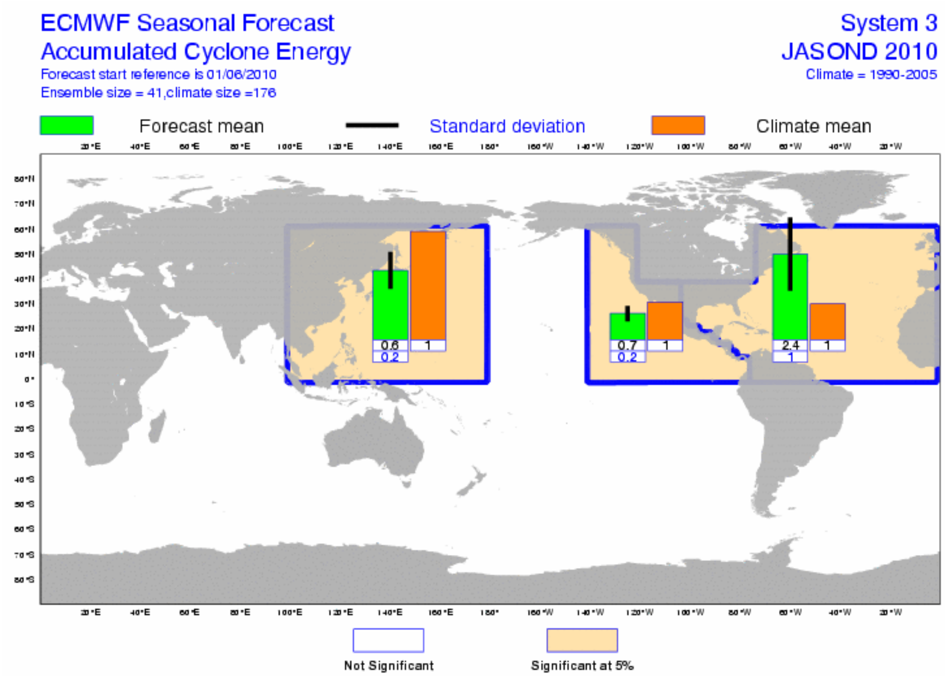


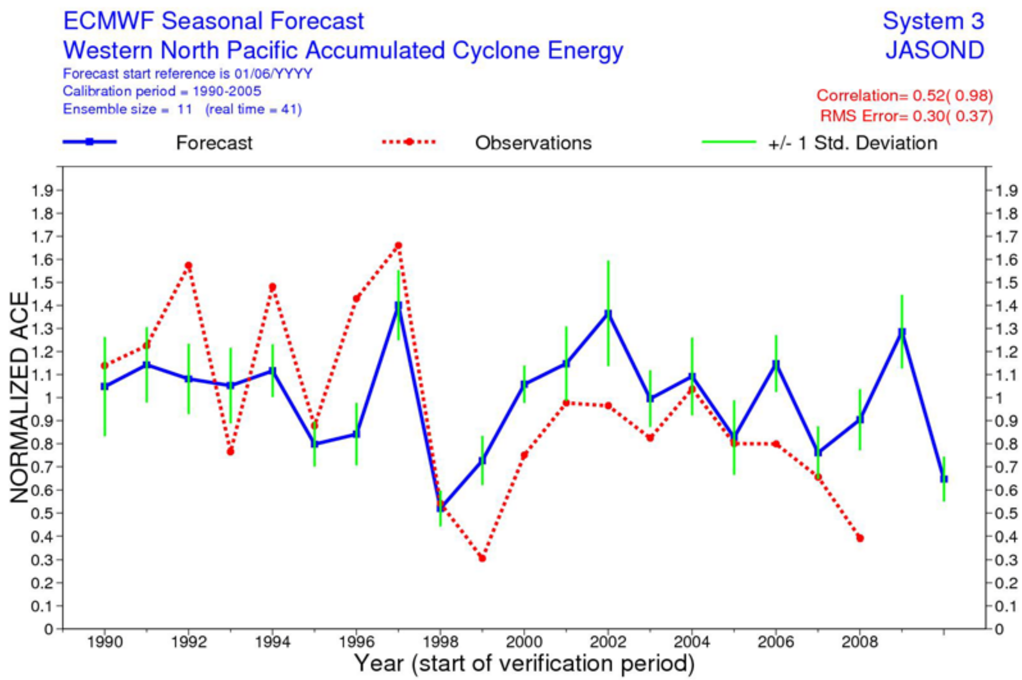


2. S3 Accumulated Cyclone Energy forecast
System 3 累積サイクロンエネルギー予報

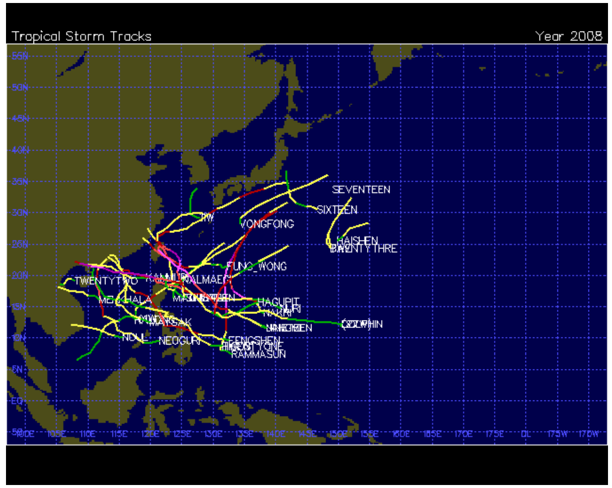
One of the operational seasonal forecasts is ACE (an index of storm activity defined by the sum of the square of the estimated maximum sustained velocity of every active tropical storm). The left panel shows the ACE forecast issued on 1 June 2010 for JASOND10.

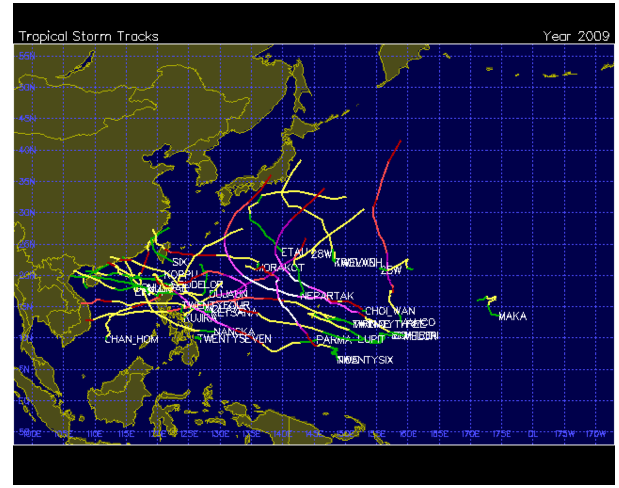
The right panel shows that the accuracy of this product over WPAC (CC 52%).





1997 1999


Tropical Storm Tracks
Year 2008
SEVENTEEN
SIXTEEN
VONGFONG
FUNG_WONG
HAGUPIT
NEOGURI
RAMMASUN


Tropical Storm Tracks
Year 2009
MORAKOT
NEPARTAK
CHOI_WAN
CHAN_HOM
TWENTYSEVEN
PARMA
LUPIT
MAKA

2. EUROSIP: ECMWF, UKMO and MeteoFrance

マルチモデル季節予報システム EUROSIP: ECMWF、イギリス気象局、フランス気象局

- Compared to medium-range forecasting, the predicted signals are much smaller and the time over which model errors accumulate are longer, so the importance of model error is much, much higher. One way to better simulate model uncertainty is to create multi-model forecasting systems by combining the output from several models, rather than taking just one model.

- The fundamental reason for the benefit of a multi-model approach is that all models have errors that have a different impact on a given forecast. By averaging across a number of models, a significant part of the model error can be reduced. Unfortunately some errors tend to be common between models, so averaging is not a panacea nor a replacement for model development.

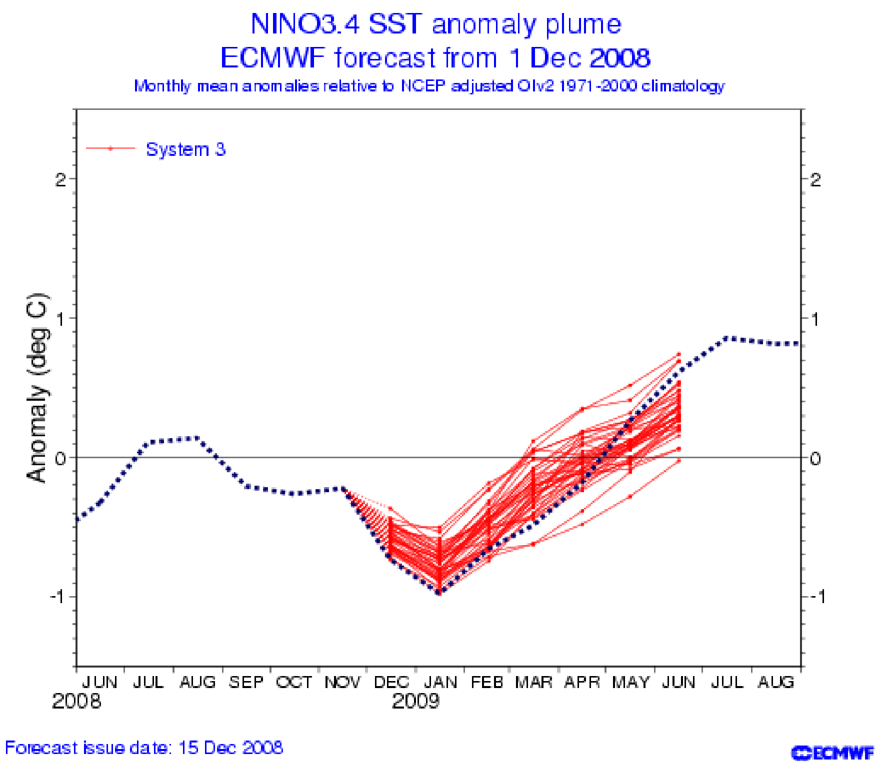
- One of these multi-model systems is EUROSIP, a multi-model seasonal forecasting system consisting of three independent coupled systems: ECMWF, Met Office and Météo-France (all integrated in a common framework).

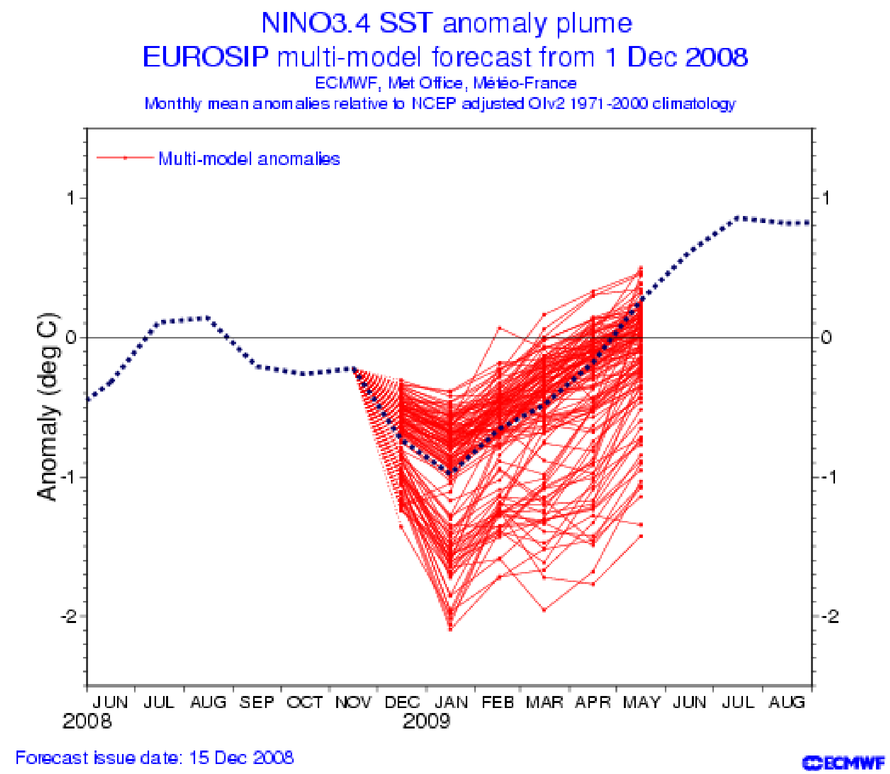
2. 6m ENSO outlook with S3 & EUROSIP: 1 Dec 08

System 3 による 6か月ENSO見通し:2008年12月1日初期値

ECMWF (left) and EUROSIP 3-system SST anomaly forecasts for NINO3.4 area issued on 1 Dec 2008 and valid for 6 months.

The observed SST anomaly lies at the edge of the ECMWF plum. Compared to the single ECMWF plum, the EUROSIP plum has a larger dispersion and gives a higher probability of cold conditions.



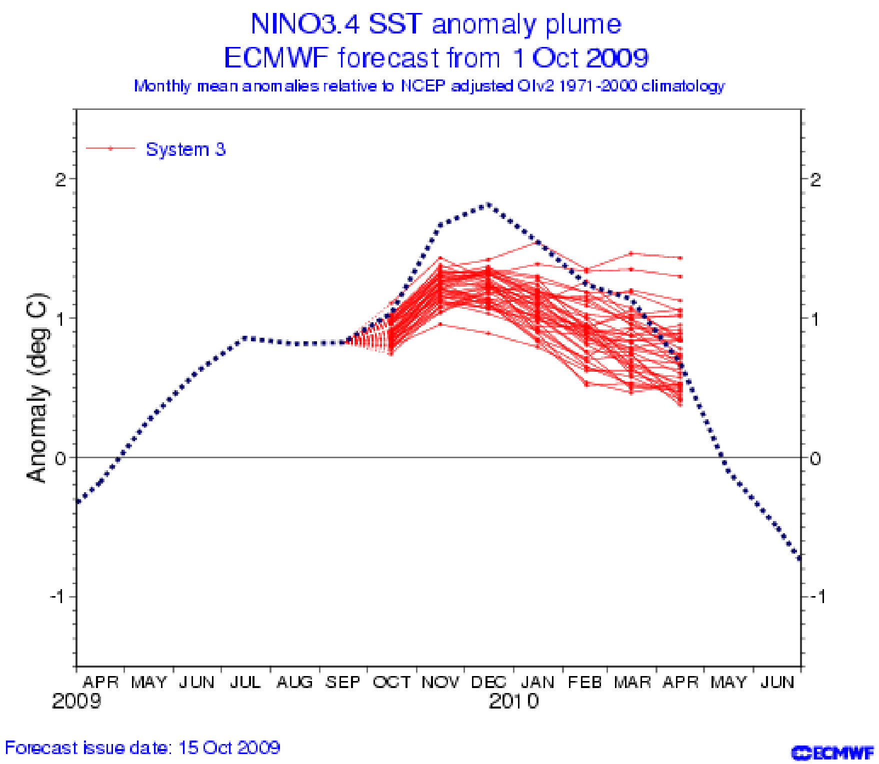


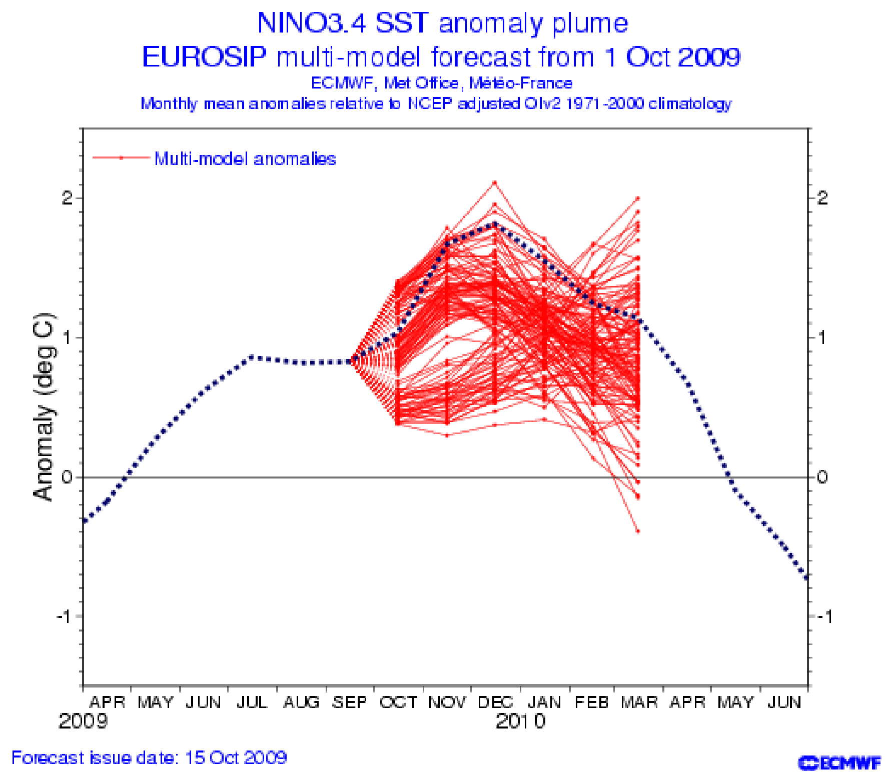
2. 6m ENSO outlook with S3 & EUROSIP: 1 Oct 09

System 3 による 6か月ENSO見通し:2009年10月1日初期値

ECMWF (left) and EUROSIP 3-system SST anomaly forecasts for NINO3.4 area issued on 1 Oct 2009 and valid for 6 months.

In this case the observed SST anomaly lies outside the edge of the ECMWF plum. Compared to the single ECMWF plum, the EUROSIP plum has a larger dispersion and includes the observed SST within the forecast range.





Outline 概要

1. ECMWF and its forecasting systems: a brief overview

   ECMWFとその予測システム：概要

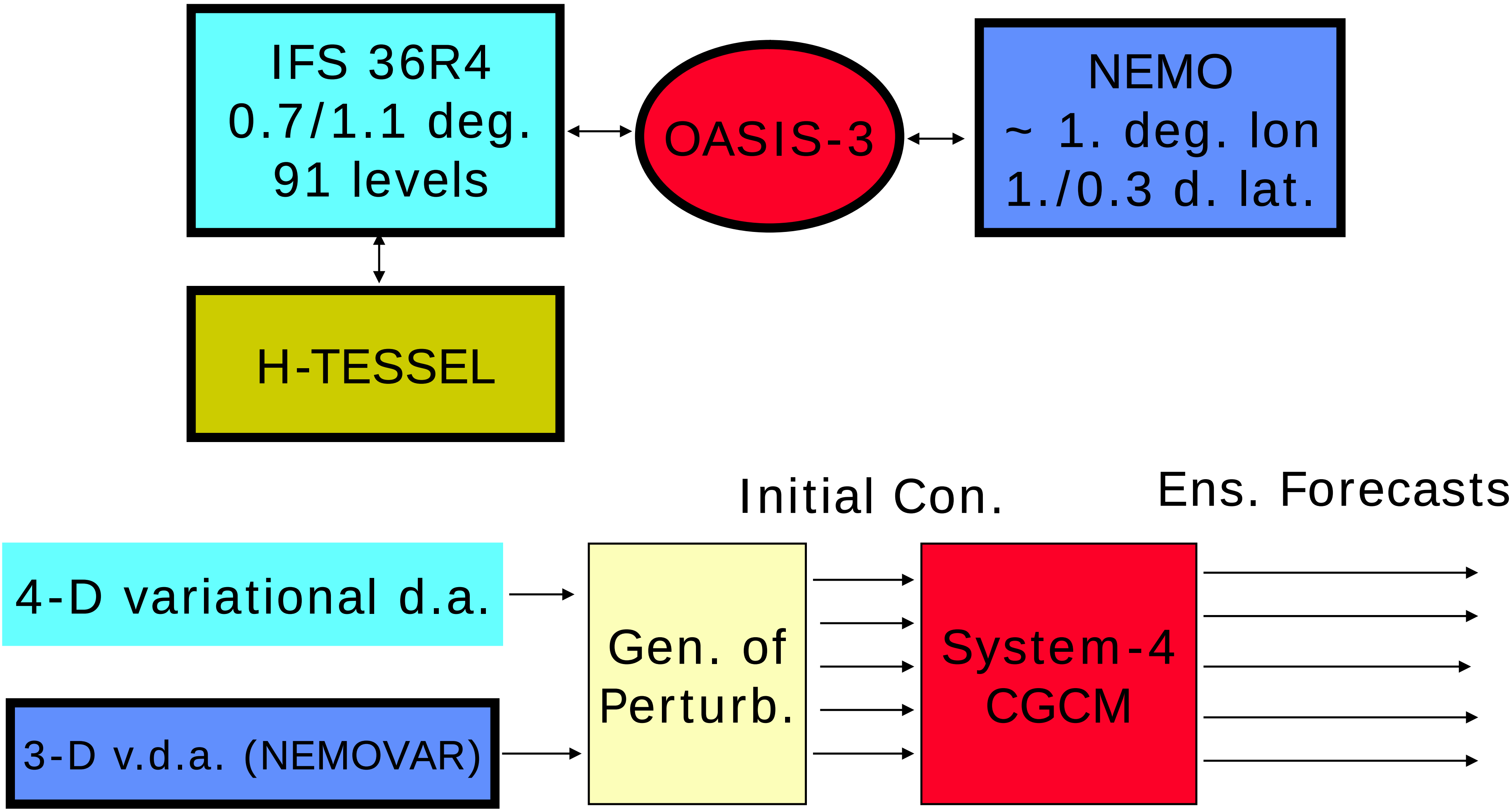
2. Coupled seasonal forecasting at ECMWF: S3 and EUROSIP

   ECMWFの結合季節予報：S3とEUROSIP

3. Future developments (S4) and conclusions

   将来の開発（System 4）と結論

3. The new seasonal forecasting system S4
新しい季節予報システム(System 4)



3. System 4: main features
System 4: 主な特徴

- New ocean model: NEMO v. 3.0 + 3.1 coupling interface
  - ORCA-1 configuration (~1-deg. resol., ~0.3 lat. near the equator)
  - 42 vertical levels, 20 levels with z < 300 m

- Variational ocean data assimilation (NEMOVAR)
  - 3-D var with inner and outer loop
  - Collaboration with CERFACS, UK Met Office, INRIA
  - First re-analysis (1957-2009), no assim. of sea-level anomalies
  - Second re-analysis and real-time system including SLA

- IFS model cycle: 36r4 (currently operational)
  - New physics package, including HTESSEL land-surface scheme, snow model (with EC-Earth), new land surface initialization

- Prescribed sea-ice concentration with sampling from recent years

3. Ocean Re-Analysis with NEMO at ECMWF
海洋モデルNEMOによる海洋再解析

- Using NEMO/NEMOVAR
- Model configuration: ORCA1, smooth coastlines, closed Caspian Sea.
- Forced by ERA40 (until 1989) + ERA Interim (after 1989)
- Assimilates Temperature/Salinity from EN3 and altimeter data
- Strong relaxation to SST (OI_v2)
- Online bias correction scheme
- First ensemble reanalysis (1957-2009) completed (COMBINE project):
  - 5 ensemble members (perturbations to wind, initial conditions, observation coverage)
  - Corrected XBT
- Second re-analysis that assimilates also altimeter data (1957-2010) just completed (and to be continued for S4)

correl (1): faz9 correl (1993-2008)

3. Future developments and conclusions
将来の開発と結論

- Ensemble-based probabilistic systems provide more complete information than single forecasts. They can be used in weather risk management to assess the probability of occurrence of events that can cause severe losses.

- ECMWF has been producing ensemble-based forecasts since 1992. Long-range seasonal forecasts are now based on 41 coupled integrations of the IFS-cy31r1 T159L62 atmospheric model and the HOPA 1.0-0.3 degree ocean model.

- ECMWF will introduce the new seasonal forecasting system 4 (S4) in 2011. S4 is based on a more accurate, higher-resolution (T255L91) atmospheric model and a better ocean model (NEMO 1.0-0.3 deg res). The ocean analysis will also change from OI to a 3D-Var data assimilation system (NEMOVAR).

- Further improvements of ECMWF seasonal forecasts are expected from better model error simulation schemes, the inclusion of dynamical sea-ice and mixed-layer (see e.g. work by *Y Takaya*, JMA) models, and higher resolution ocean models. The possibility to merge the 15/32d EPS and the 7/14m SF systems into a Seamless Probabilistic System is also been considered.