Progrès Récents et Perspectives de Recherche au Centre Européen de Prévisions Météorologiques à Moyen Terme (CEPMMT – ECMWF)

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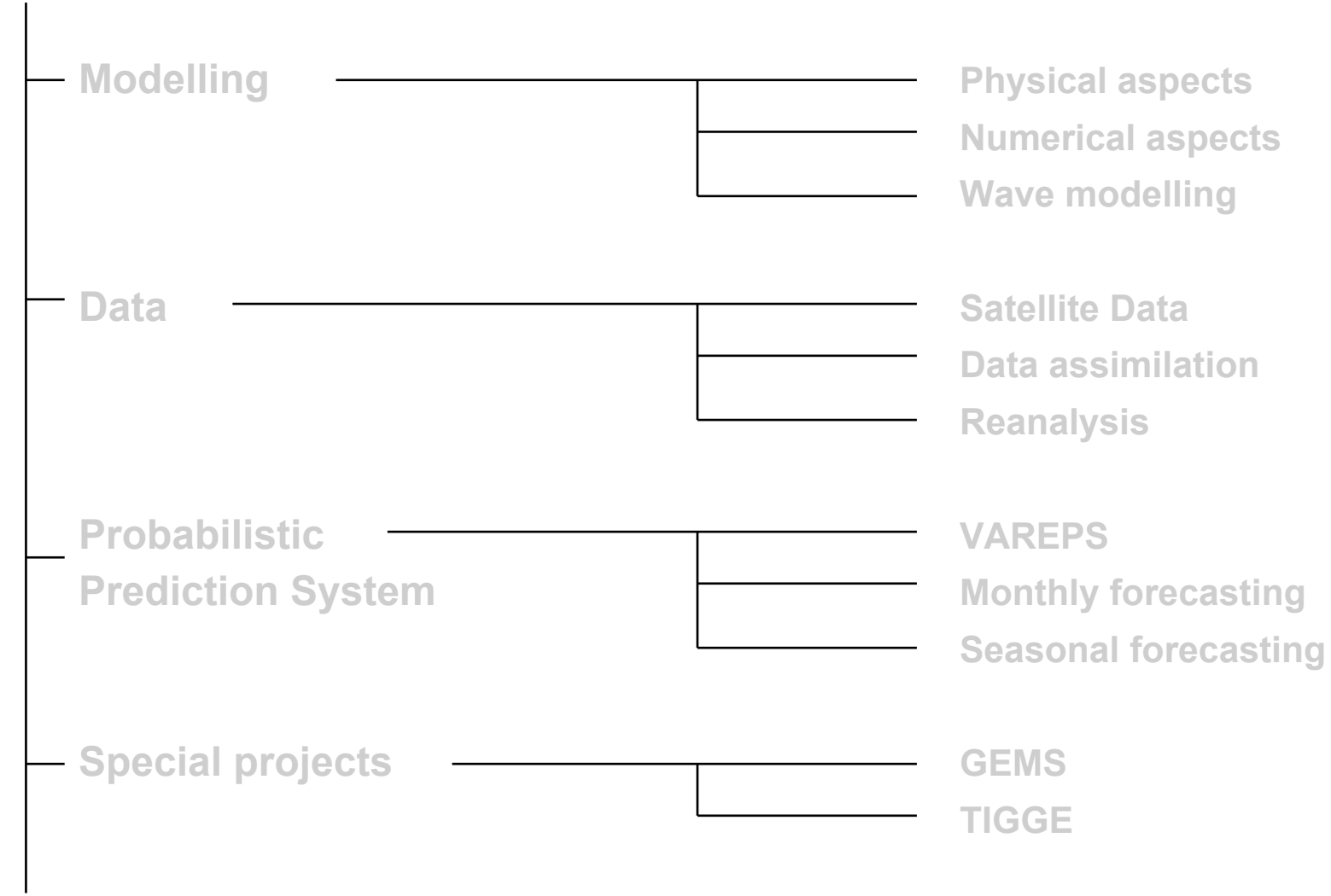
Introduction

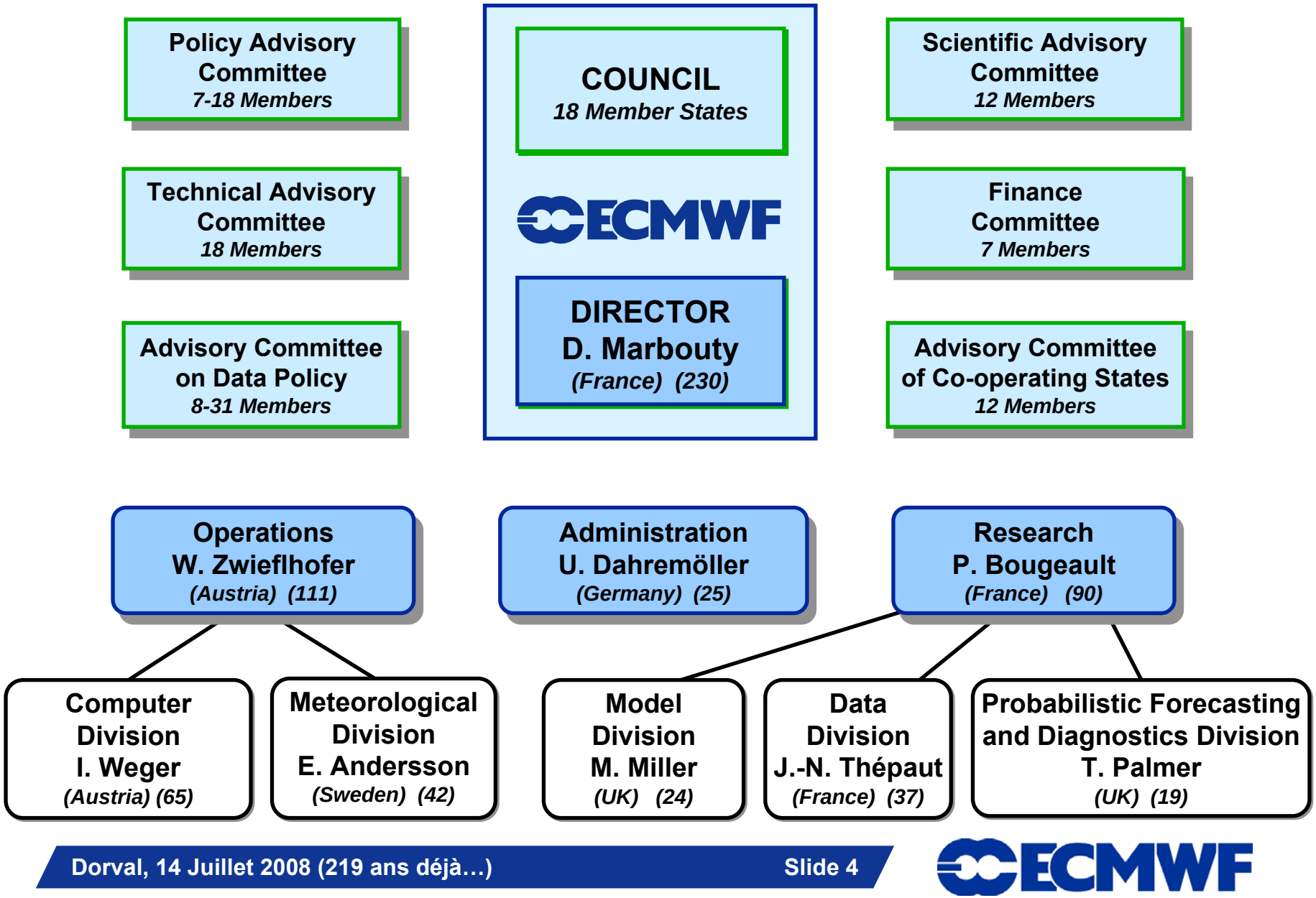
- Modelling
  - Physical aspects
  - Numerical aspects
  - Wave modelling
- Data
  - Satellite Data
  - Data assimilation
  - Reanalysis
- Probabilistic Prediction System
  - VAREPS
  - Monthly forecasting
  - Seasonal forecasting
- Special projects
  - GEMS
  - TIGGE

Outlook

Introduction



Organisation of ECMWF



ECMWF

Summary of the strategy for ECMWF 2006 – 2015 (1/2)

A Strategy for ECMWF for the period 2006 to 2015 was adopted unanimously by the ECMWF Council in December 2005.

In summary:

Principal Goal

- **The principal goal of ECMWF in the coming ten years will be to maintain the current, rapid rate of improvement of its global, medium-range weather forecasting products, with particular effort on early warnings of severe weather events**

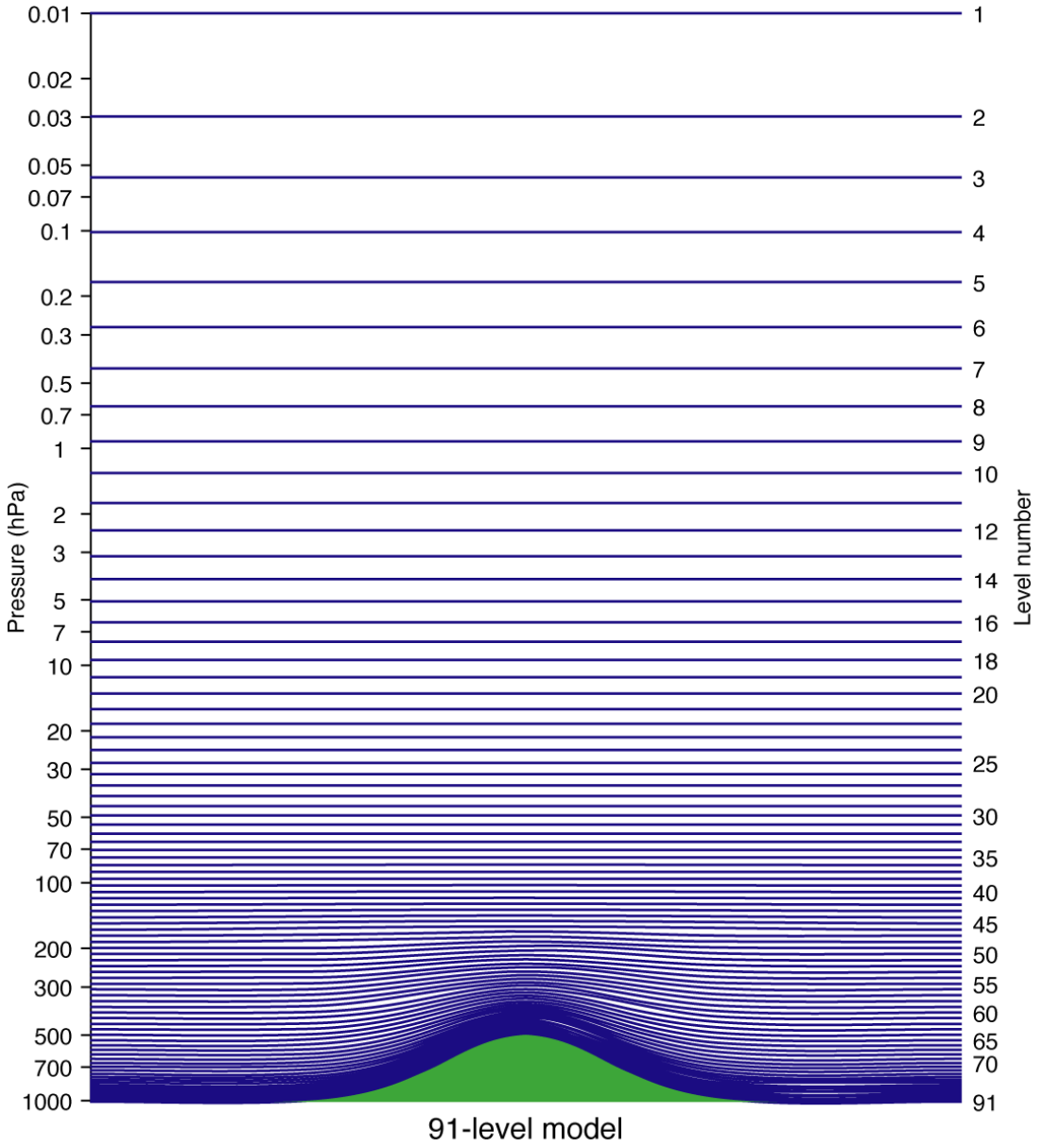
Summary of the strategy for ECMWF 2006 – 2015 (2/2)

- **Complementary goals:**
  - **To improve the quality and scope of monthly and seasonal-to-interannual forecasts**
  - **To enhance support to Member States national forecasting activities by providing suitable boundary conditions for limited-area models**
  - **To deliver real-time analyses and forecasts of atmospheric composition**
  - **To carry out climate monitoring through regular re-analyses of the Earth-system**
  - **To contribute towards the optimization of the Global Observing System.**

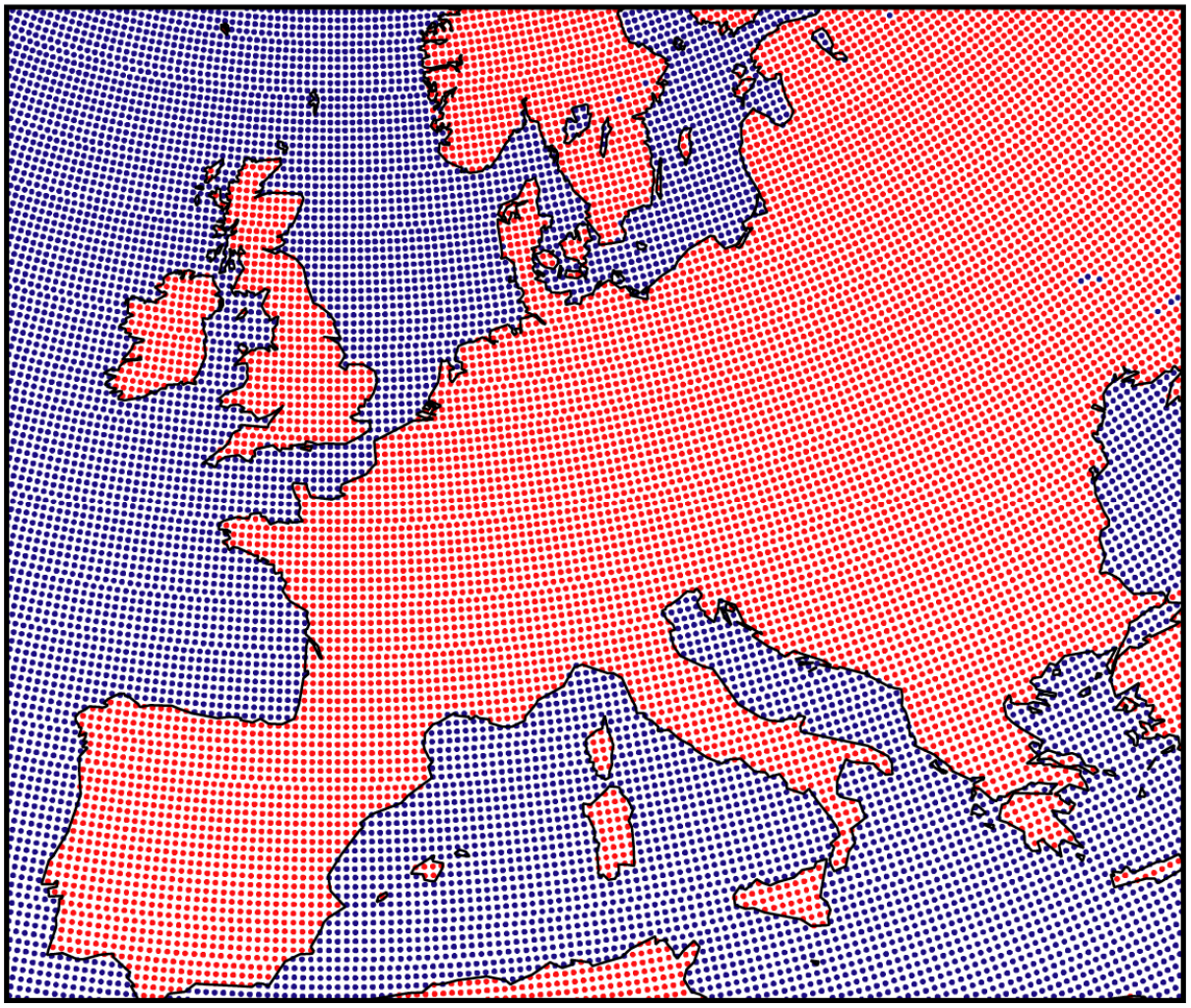
The operational forecast system: 2008

- **Data assimilation:** twice per day
  12-hour 4D-Var 25 km 91-level; 210/125/80 km minimisations
- **High resolution deterministic forecast:** twice per day
  25 km 91-level, to 10 days ahead
- **Ensemble forecast (EPS):** twice daily
  51 members, 62-level, 50 km to 10 days, then 80 km to 15 days
- **Ocean waves:** twice daily
  Global: 10 days ahead at 40 km; EPS 15 days ahead at 100 km
  European Waters: 5 days ahead at 25 km
- **Monthly forecast:** once a week (coupled to ocean model)
  51-members, 50/80 km 62 levels, to one month ahead
- **Seasonal forecast:** once a month (coupled to ocean model)
  41 members, 125 km 62 levels, to seven months ahead
- **Boundary Conditions:** short cut-off analyses based on 6-hourly 4D-Var initiating a forecast to 3 days, four times per day

Operational model levels (91-level model)



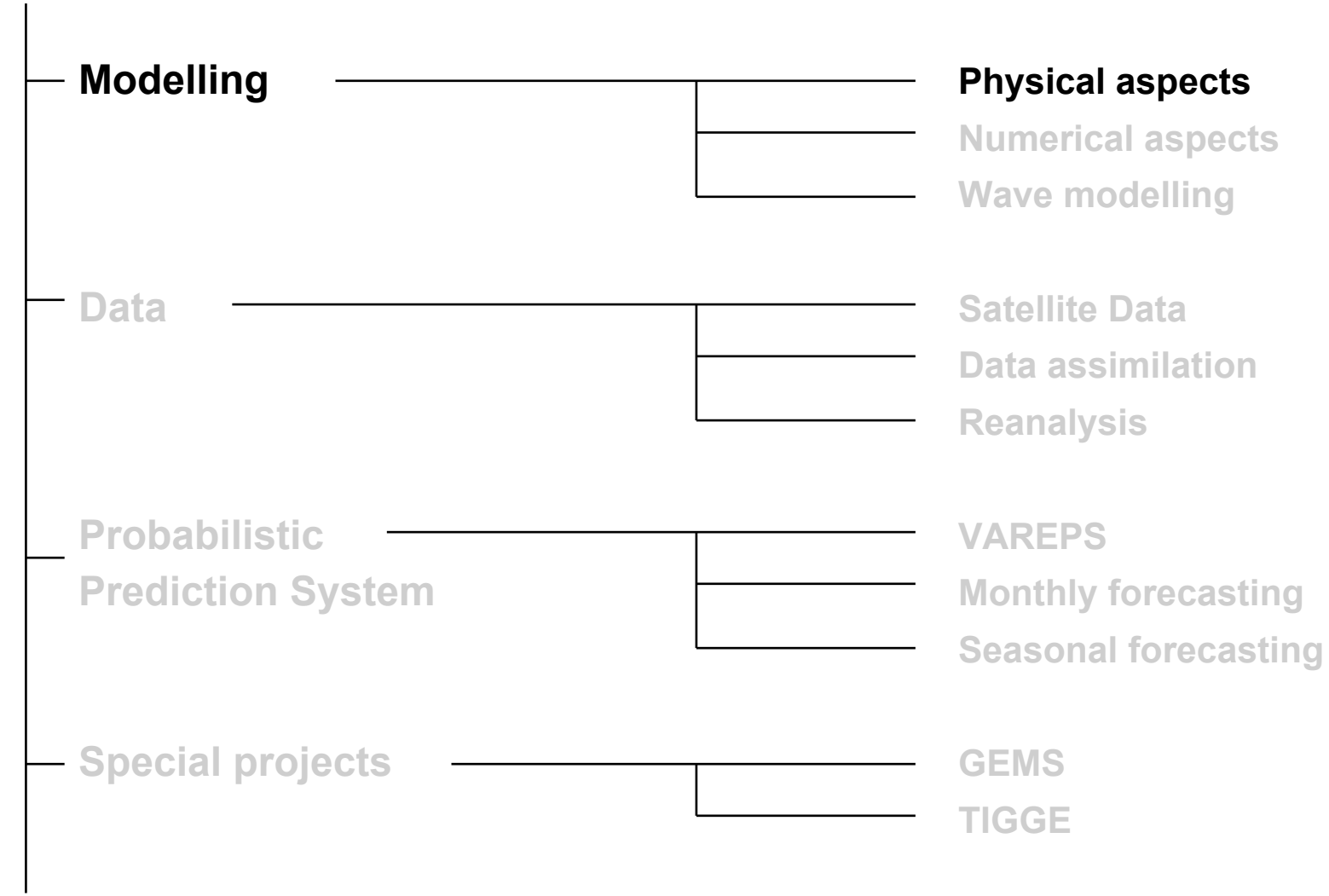
Operational model grid



Highlights from recent implementations

- **T799/L91 higher-resolution forecast system.**
- **Variable-resolution ensemble prediction system (VAREPS) to 15 days.**
- **Significant improvements of model physics.**
- **New satellite data assimilated:**
  - **METOP-A instruments,**
  - **MTSAT AMVs + COSMIC GPS radio occultation,**
  - **More microwave radiances (AMSR-E, TMI and SSMIS),**
  - **More SBUV ozone retrievals and assimilation of OMI (AURA).**
- **New moist linear physics in 4D-Var, and 3rd outer loop: now minimizing at T95 → T159 → T255.**

Introduction



Outlook

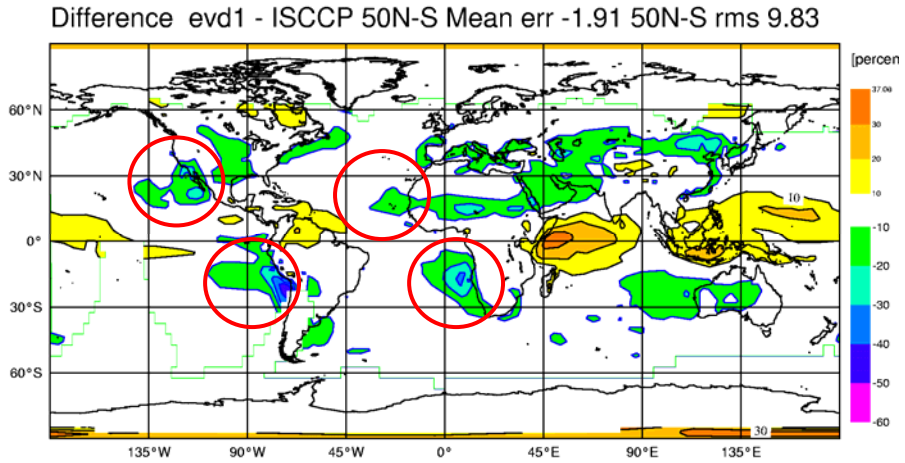
Physical Aspects

- **A rapidly changing model:**
  - **Reduction of vertical diffusion above the PBL.**
  - **New shortwave radiation scheme and McICA.**
  - **Changes to entrainment and closure of deep convection scheme.**
  - **New soil hydrology (texture and run-off): H-TESSEL.**
  - **Super-saturation with respect to cloud ice, changes to ice particle size and fall speed.**

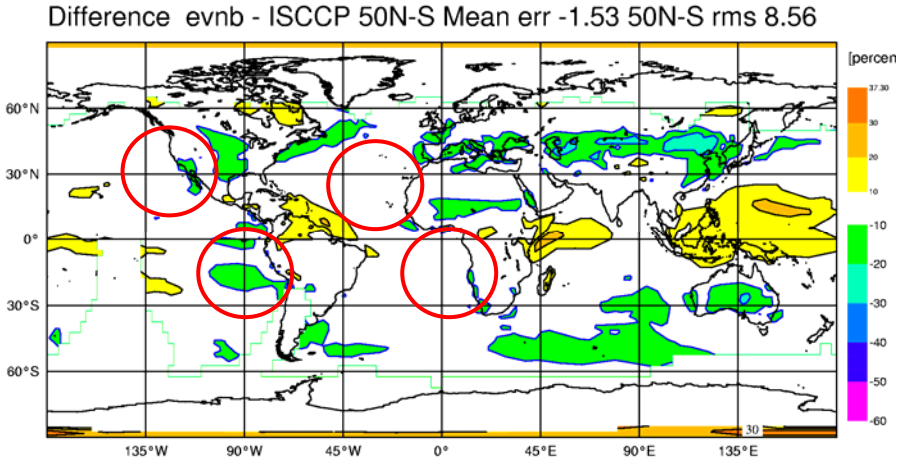
- **and soon:**
  - **New shallow convection scheme.**
  - **Mass flux momentum transport in vertical diffusion.**
  - **New description of vegetation (ECOCLIMAP).**
  - **Effect of gravity waves in the middle atmosphere.**

Impact of reduced vertical diffusion on cloud cover - verified against ISCCP

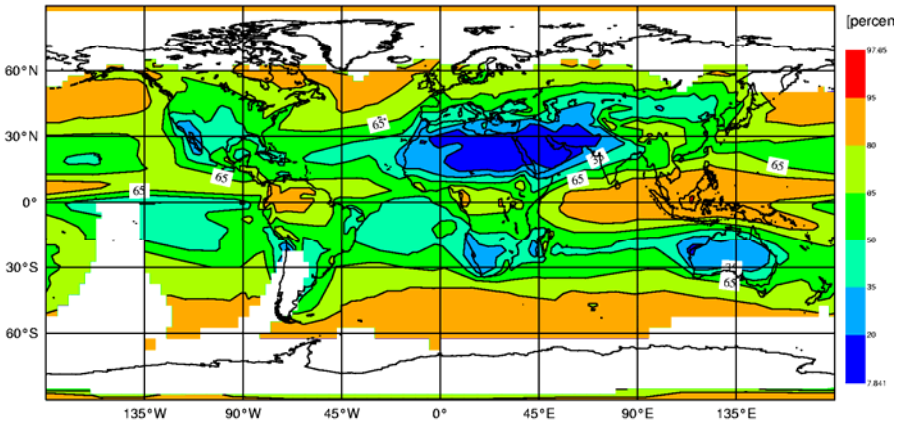
Old - ISCCP



New - ISCCP



ISCCP observed total cloud cover

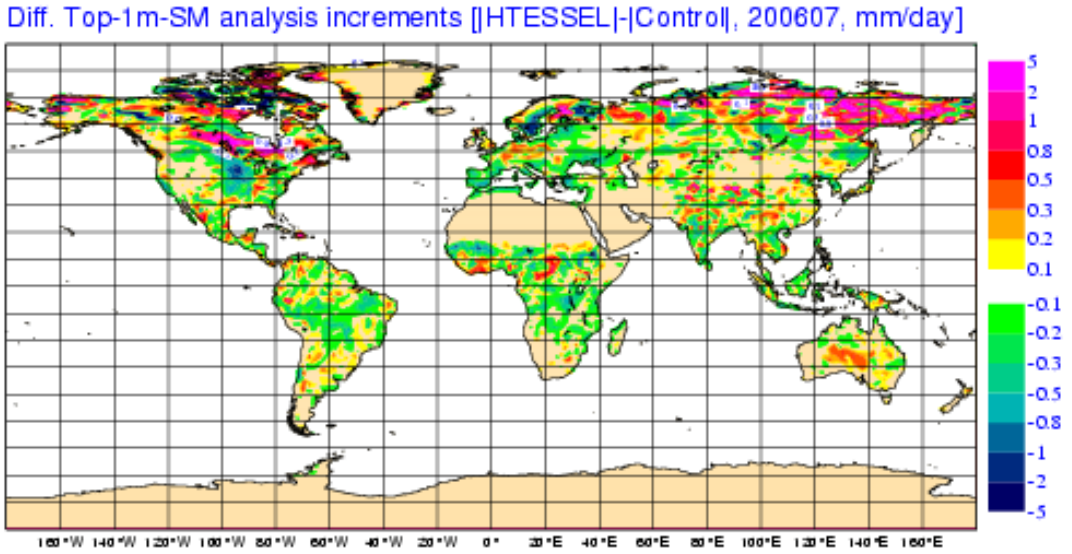


ECMWF

A new surface scheme (H-TESSEL)

- **Using a map of 6 soil textures; assigning hydraulic properties, wilting point and field capacity are based on soil texture.**
- **New surface run-off scheme based on sub-grid orography.**

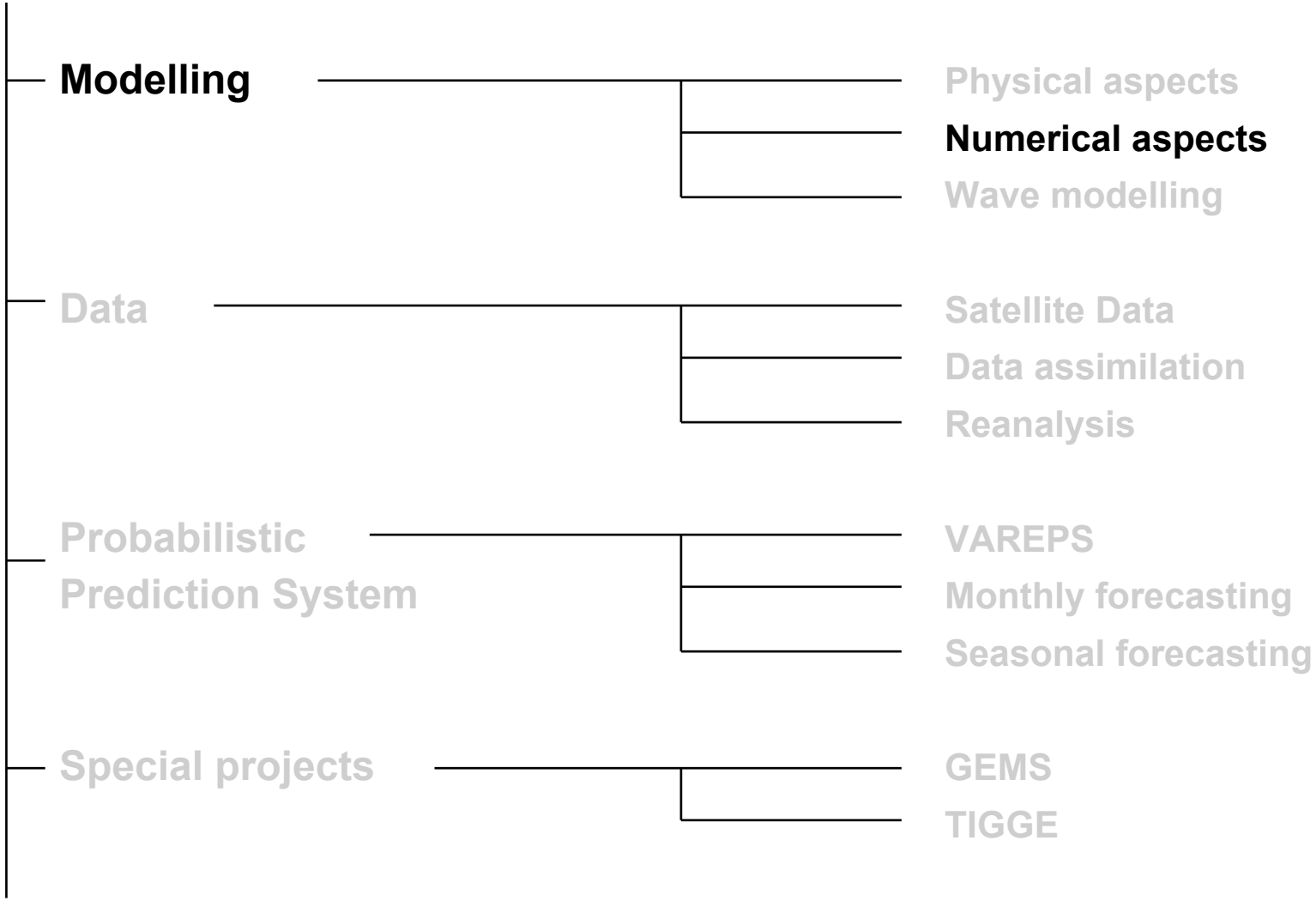
- *Most regions now have a larger soil water capacity and dry slower during the dry season.*
- *Increase of surface run-off in the case of dry soils.*



July 2007, in T159L91 experiment (01/04-01/11/2006)

Reduction in soil moisture analysis increments indicates better model.

Introduction



Outlook

ECMWF

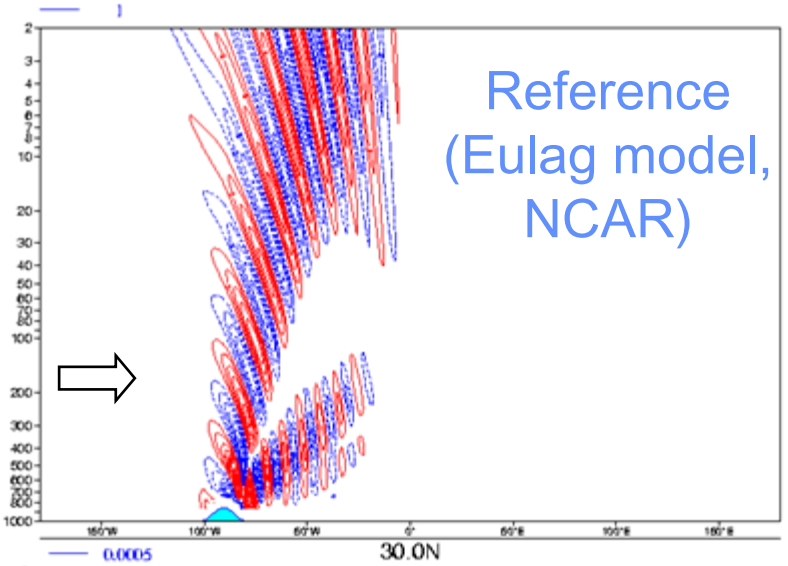
Numerical Aspects

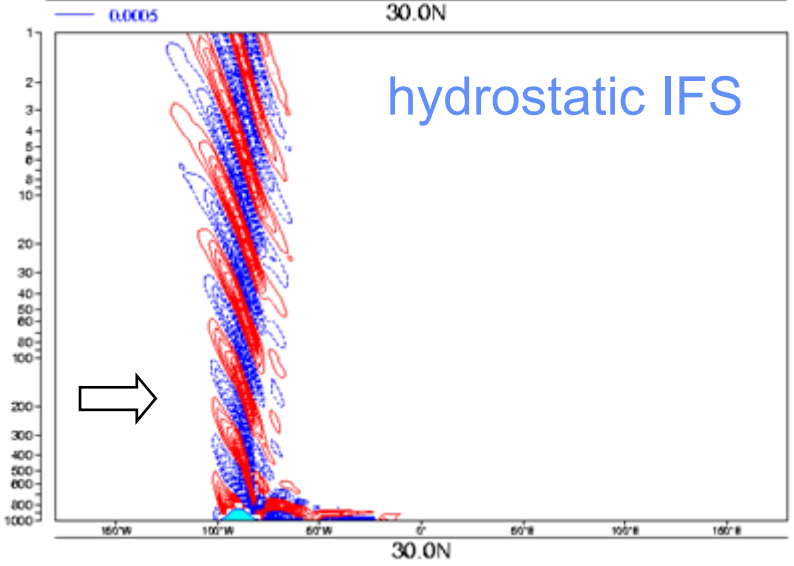
- **Implementation of the T799/L91 model.**
- **Non-hydrostatic (NH) dynamical core (Aladin/Météo-France model):**
  - **Improving the stability (time steps, iterations) and efficiency of the NH model.**
  - **How to couple the physical parameterizations to the dynamics within the iterative centred implicit (ICI) scheme used for stability in the NH dynamics?**
  - **Developing a finite-elements scheme for the vertical in the NH model.**
  - **Setting up a test-bed for non-hydrostatic effects (to accomplish high spatial resolution with coarse wavenumber cut-off).**
- **Other projects:**
  - **Fully non-interpolating semi-Lagrangian scheme.**
  - **Preparation for the next horizontal resolution increase to T1279L91 (planned for late 2009).**
  - **Improvements to the heterogeneous ozone chemistry (in collaboration with Météo-France).**

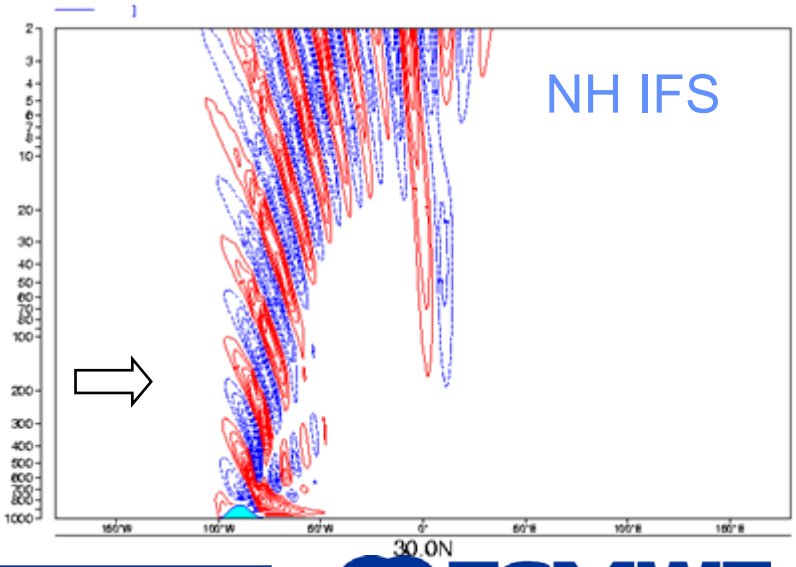
Numerical test-bed for Non Hydrostatic effects

(Cooperation with Météo-France and NCAR)

Vertical velocity for a flow past a 3D - mountain on the sphere of a "reduced Earth" (r = 60km , T159, dx = 1.2km)

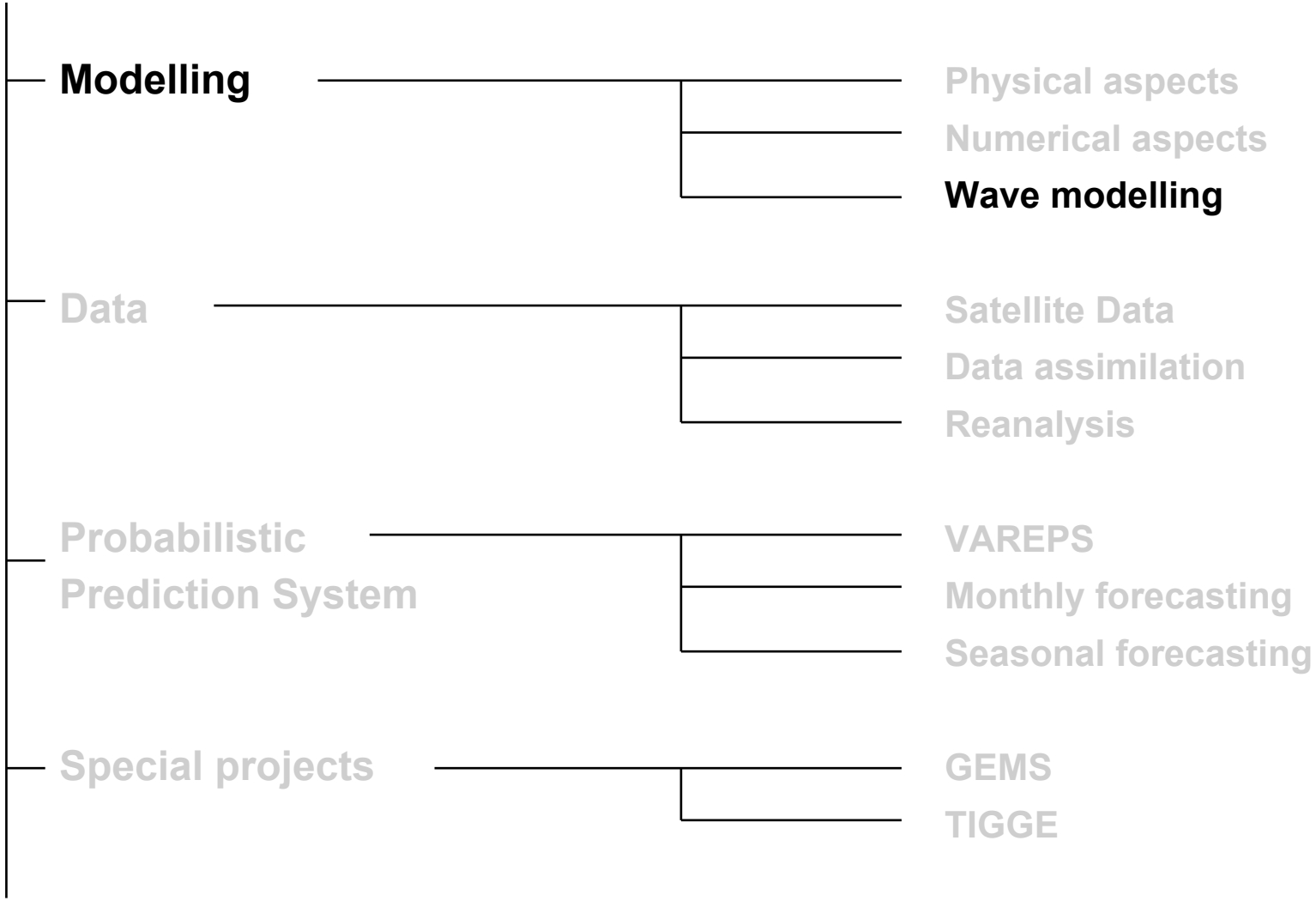






ECMWF

Introduction



Outlook

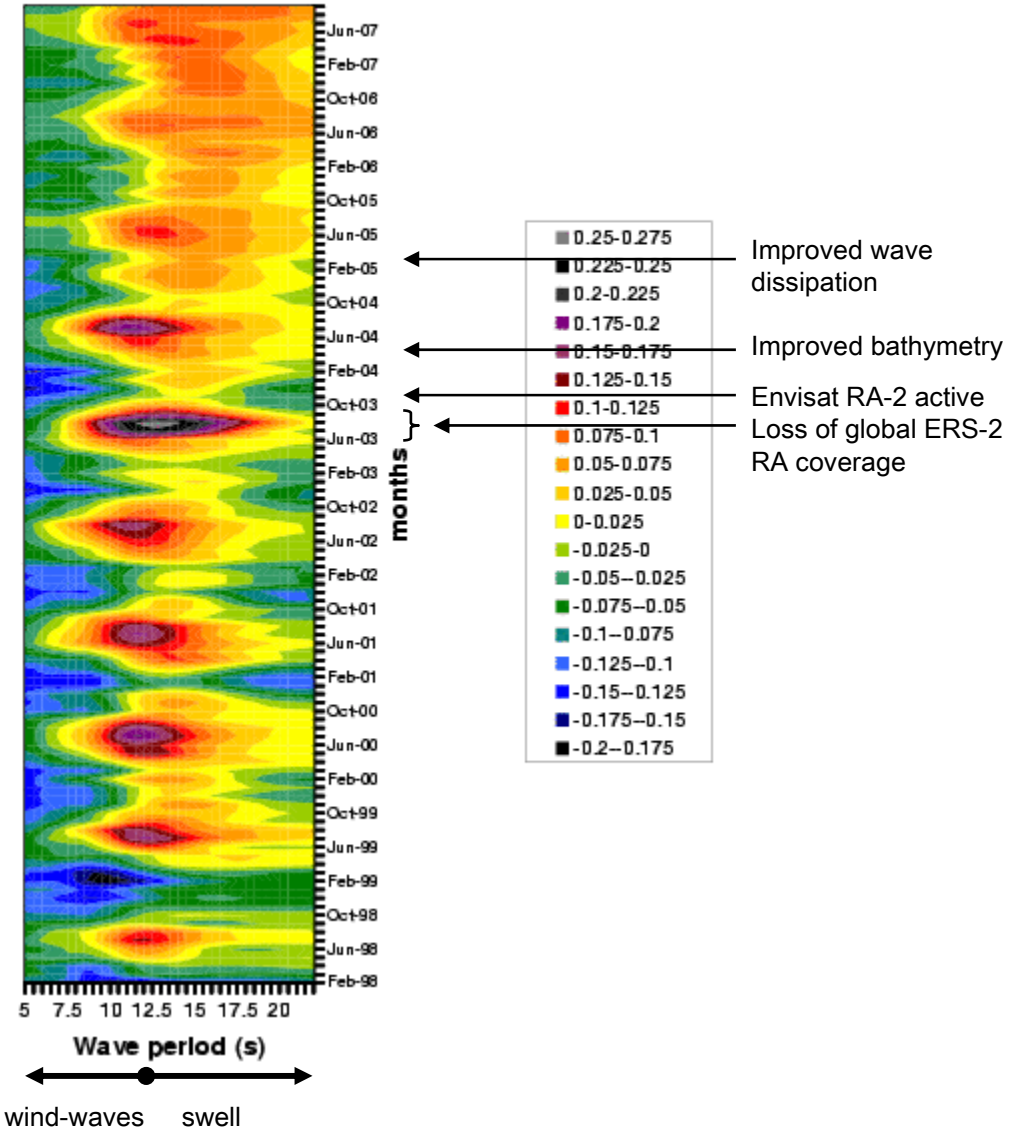
Ocean waves

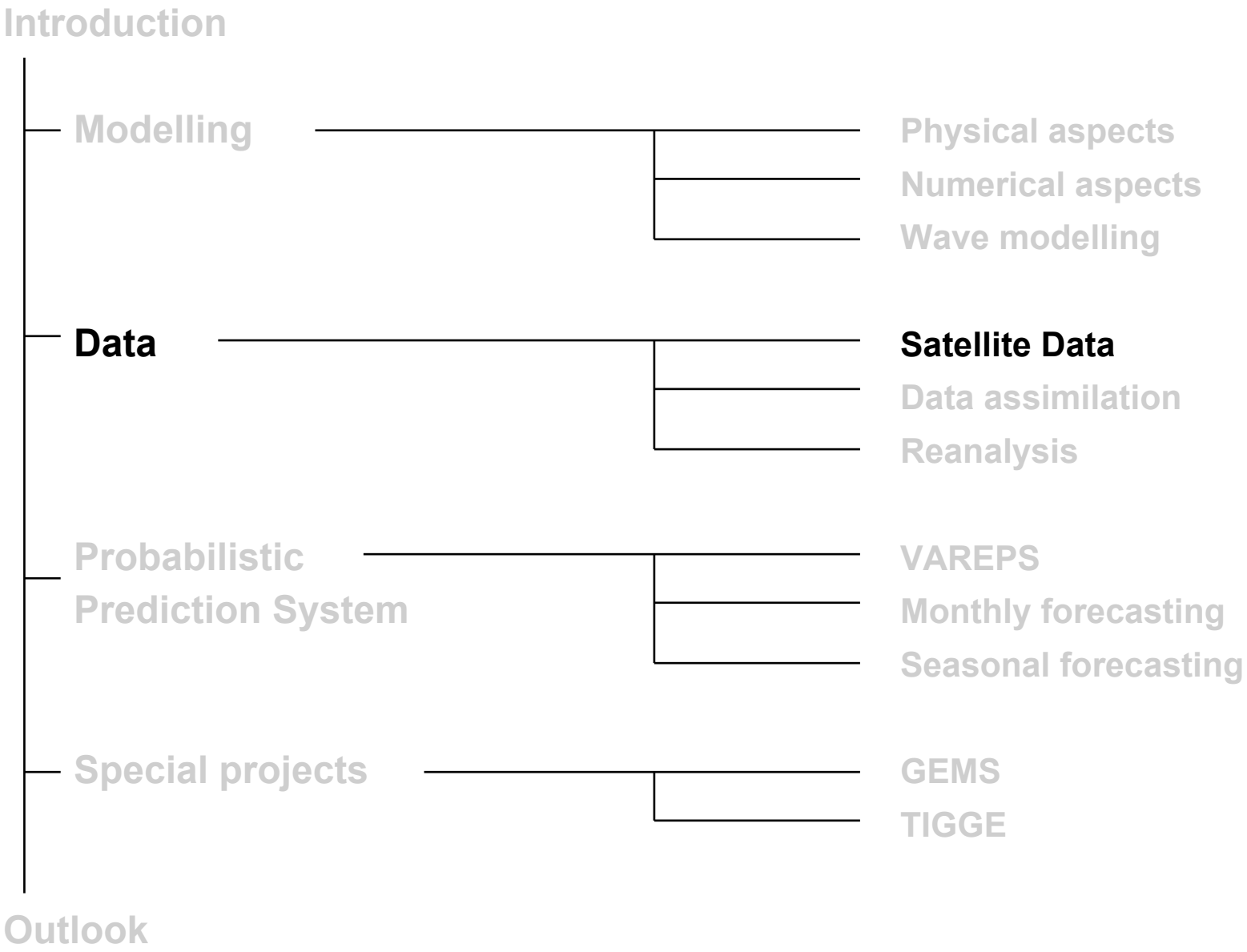
- **Change of the representation of energy dissipation by white-capping.**
- **Introduction of effects of unresolved bathymetry.**

Prominent wave forecasting example: swell at La Réunion.

- *New wave products: e.g. maximum wave height and corresponding period.*
- *A higher-resolution limited area model.*
- *Including stability effects in the scatterometer observation operator (wind stress - 10m wind speed), and accounting for ocean currents (wind stress relative to current).*

Equivalent wave height bias (model-buoy)
at all US and Canadian buoys.
Operational analysis

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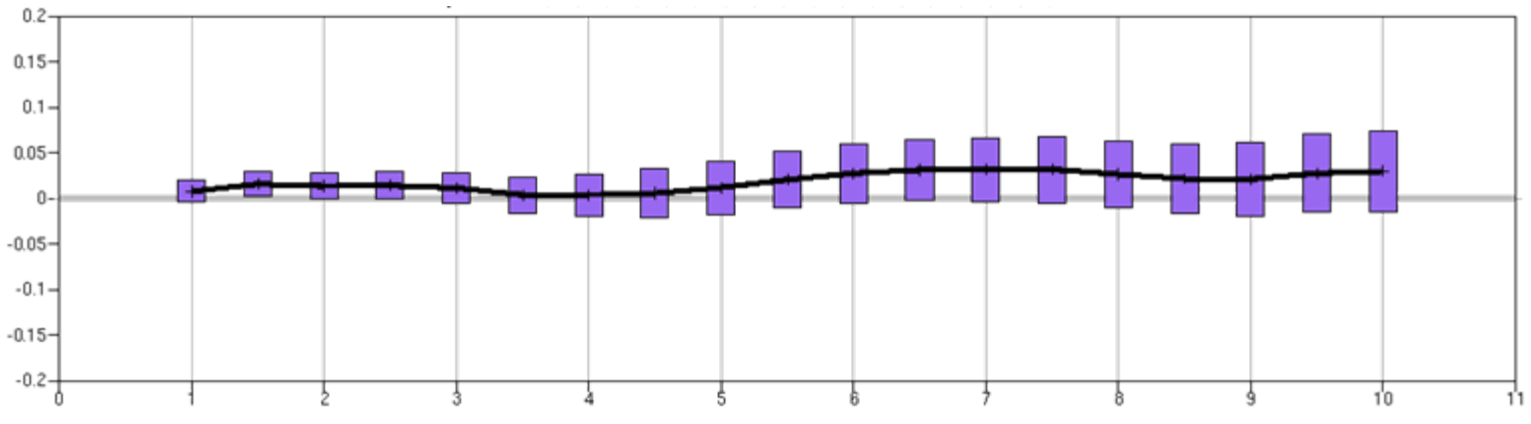
Satellite data

- **A rapidly changing observing system:**
  - **METOP data assimilated since 11 January (AMSU-A/MHS), 19 March (HIRS) 7 June (IASI, ASCAT).**
  - **GPS RO: rising occultations from COSMIC in Cy32r3, GRAS data under assessment, CHAMP/GRACE data for back-up.**
  - **Rain-affected radiances: problems of 1D+4D method are better understood.**
  - **Work on microwave land surface emissivity for better usage of sounder data over land.**
  - **Replacement of Meteosat 5+8 with 7+9, addition of MTSAT, enhanced ozone monitoring/assimilation (Envisat, METOP, AURA), more polar AMVs (MODIS).**
  - **Addition of METOP GRAS**
- **and soon:**
  - **Addition of METOP GOME-2.**
  - **4D-Var microwave radiance assimilation in presence of clouds/rain.**
  - **Evaluation of cloud-affected radiances for most IR-instruments.**
  - **Improved usage of advanced sounder data (e.g. water vapour).**
  - **Preparations for NPP (NPOESS Preparatory Project: ATMS, CrIS, OMPS, VIIRS).**

IASI Forecast Scores

500 hPa geopotential anomaly correlation (normalized difference)

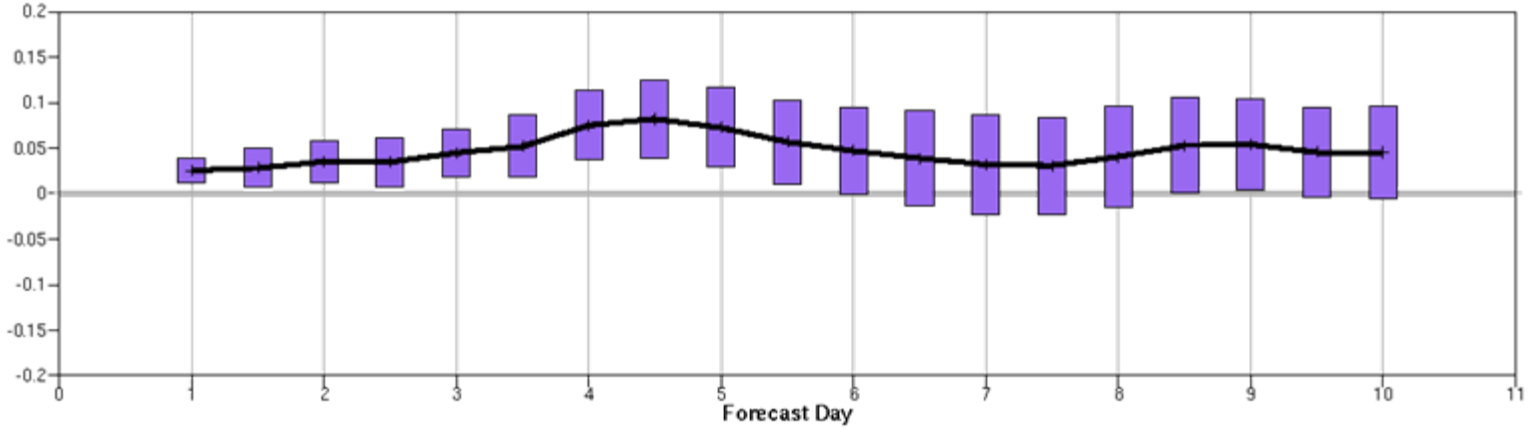
NH



IASI better

IASI worse

SH

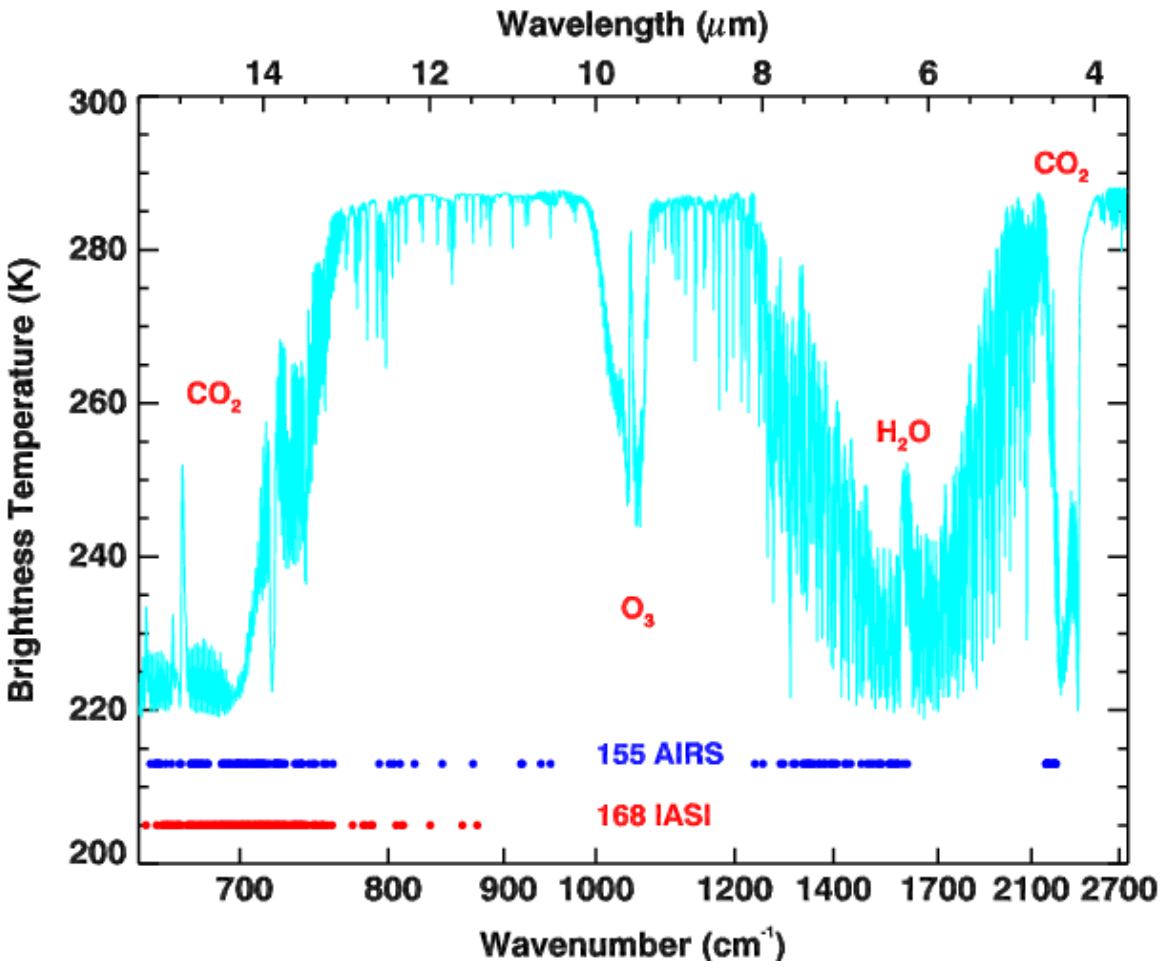


IASI better

IASI worse

ECMWF

Comparison of actively assimilated channels



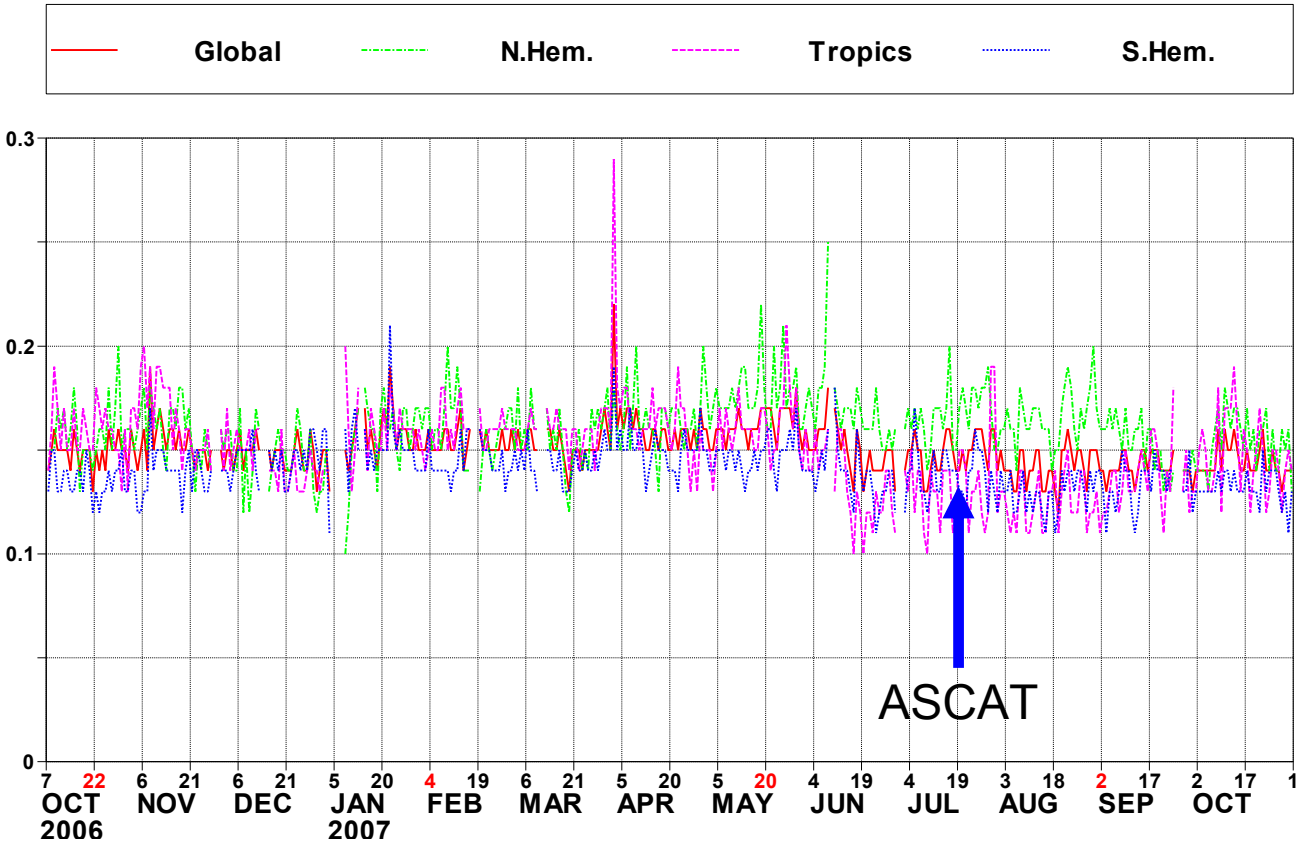
AIRS

- Operational at ECMWF since October 2003.
- 324 channels received in NRT.
- One FOV in nine used.
- Up to 155 channels may be assimilated (CO_2 and H_2O bands).

IASI

- Operational at ECMWF since June 2007.
- 8461 channels received in NRT.
- All FOVS received; only 1-in-4 used.
- 366 Channels routinely monitored.
- Up to 168 channels may be assimilated (CO_2 band only).

Assimilation of scatterometer winds from METOP's ASCAT instrument



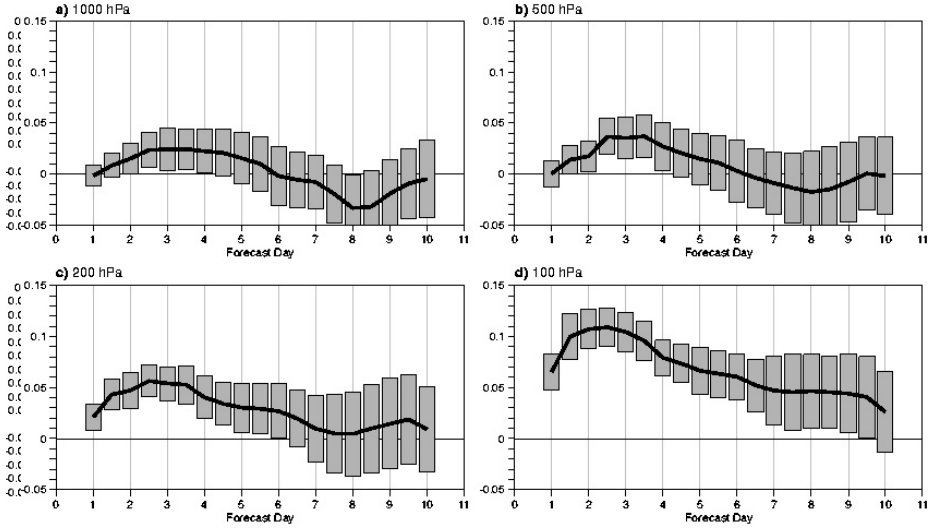
METOP ASCAT winds have been monitored since January and assimilated since 12 June 2007:

- **A bias of 1 m/s has been identified, otherwise data quality is found very high.**
- **Verification against independent data (ENVISAT altimeter winds) shows good impact.**

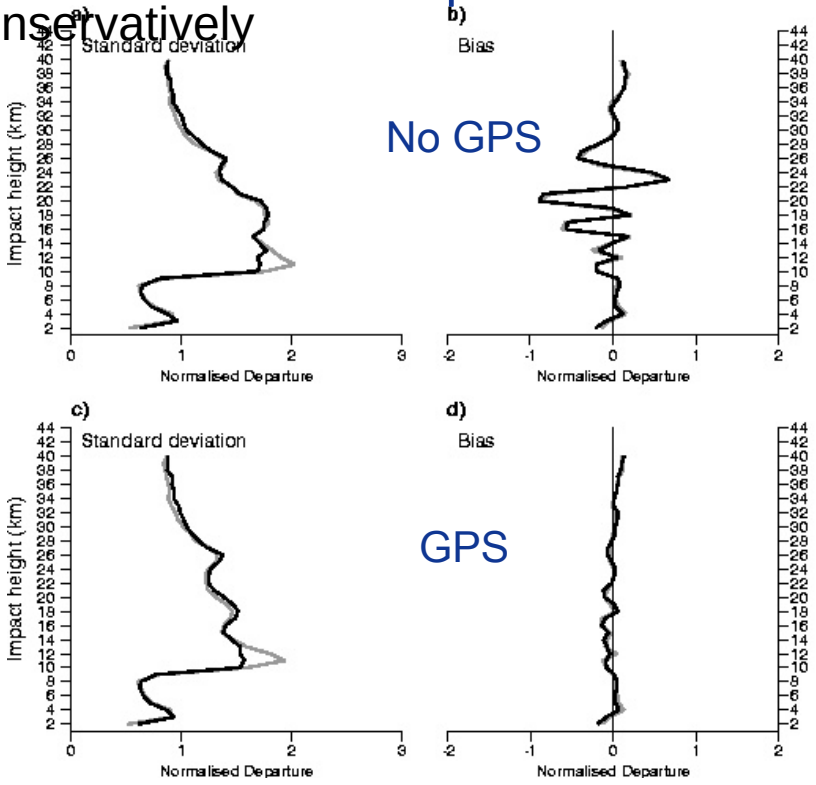
Assimilation of GPS radio occultations

- COSMIC bending angles assimilated (both setting and rising occultations), CHAMP, GRACE as back-up.
- The spread of the 6 COSMIC orbits is now optimal, positive impact now visible also at 500 hPa.
- RO data reveals a warm bias of aircraft observations.
- Substantial improvement of stratospheric T-biases.
- METOP GRAS data recently implemented conservatively (small positive impact).

SH
(normalized AC differences)



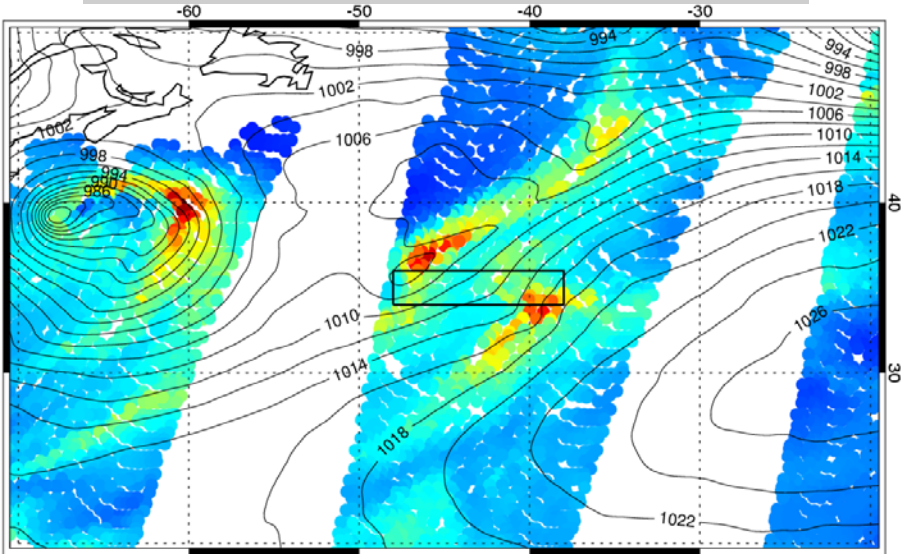
Normalized COSMIC-3 FG-departures



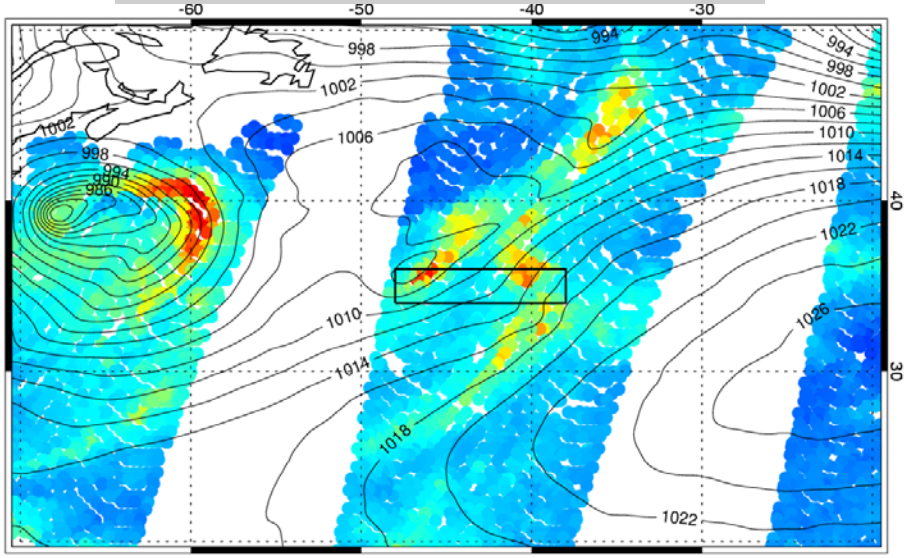
Assimilation of rain-affected microwave radiances

- Assimilation of rain-affected SSM/I radiances in 1D+4D-Var active since June 2005.
- Main difficulties: inaccurate moist physics parameterizations (location/intensity), formulation of observation errors, bias correction, linearity.
- Major improvements accomplished in 2007 and SSMIS, TMI, AMSR-E data included.
- Direct 4D-Var radiance assimilation envisaged for 2008.

4D-Var first guess SSM/I ΔTb 19v-19h [K]



SSM/I observational ΔTb 19v-19h [K]



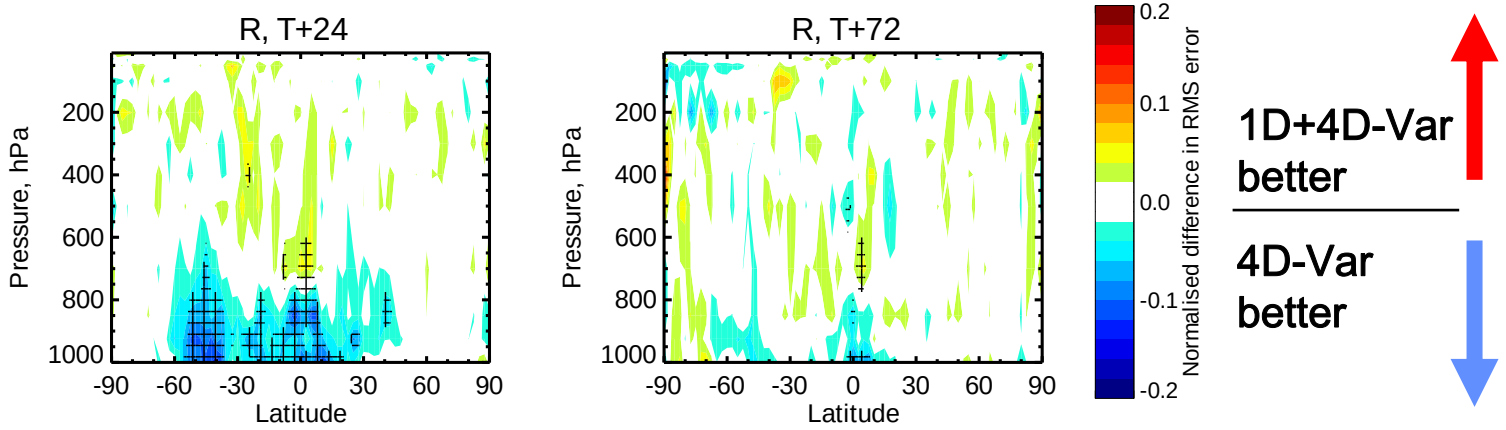
ECMWF

Assimilation of rain-affected microwave radiances

4D-Var minus 1D+4D-Var CY32R1 (against own analysis)

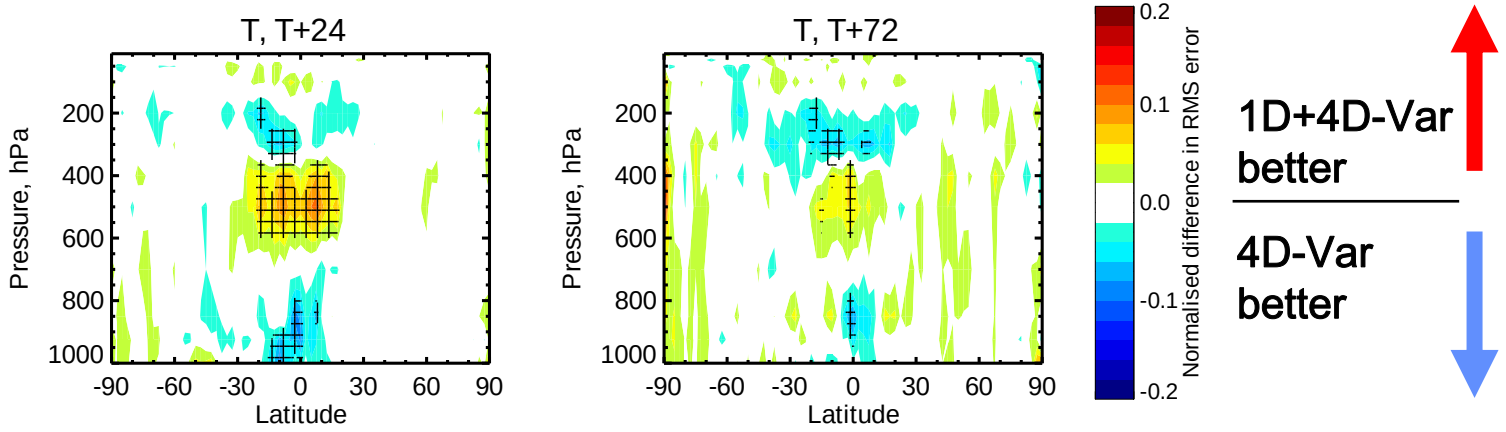
Relative humidity

RMS forecast errors (evxt-evxz), 7-Jan-2007 to 12-Feb-2007, from 31 to 37 samples.



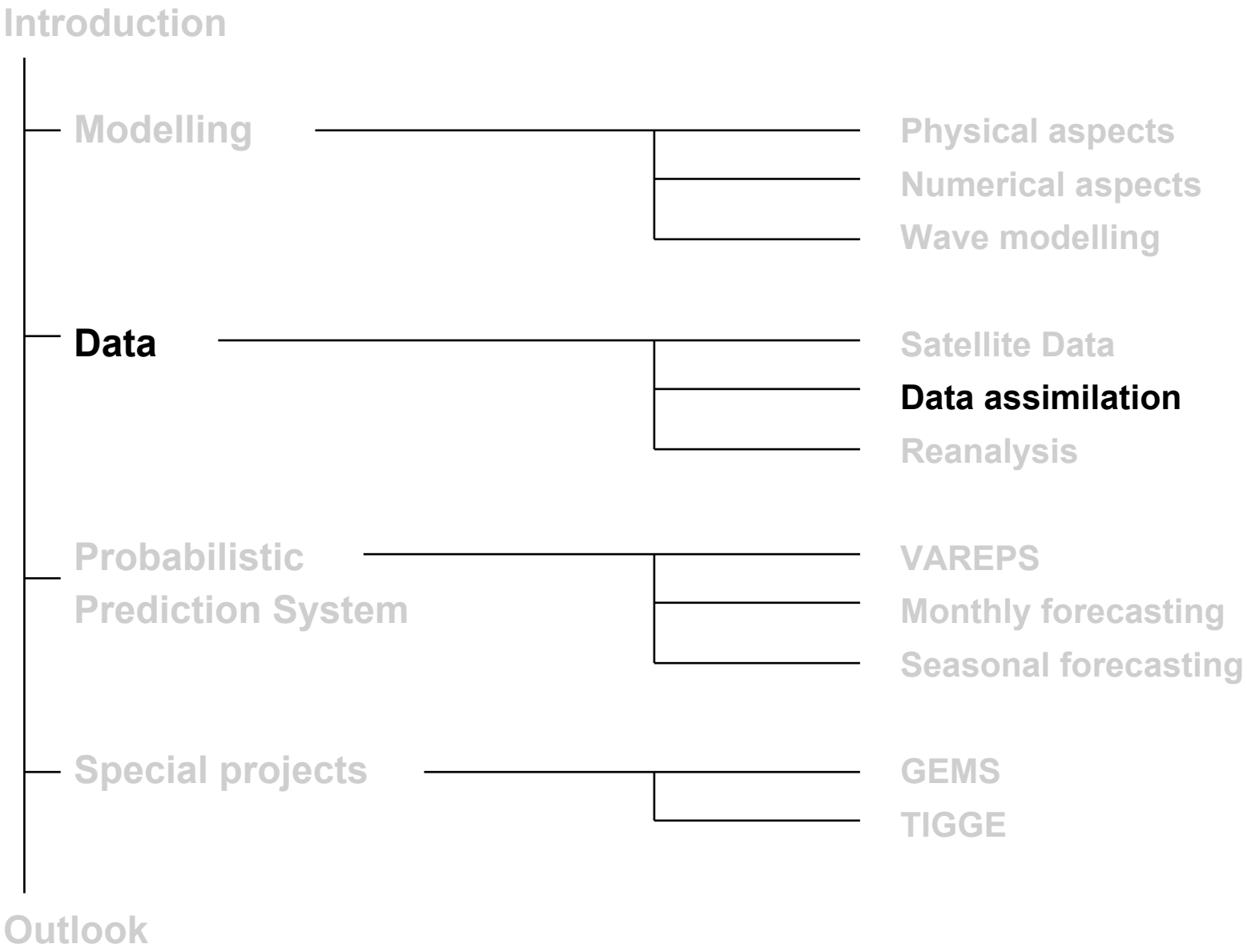
Temperature

RMS forecast errors (evxt-evxz), 7-Jan-2007 to 12-Feb-2007, from 31 to 37 samples.



(hatched areas indicate where scores are statistically significant)

ECMWF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Data assimilation

Recent implementations:

- Radiosonde bias correction (T and q, solar radiative heating effects).
- 3rd outer loop (T95 – T159 – T255).

Expected in 2009:

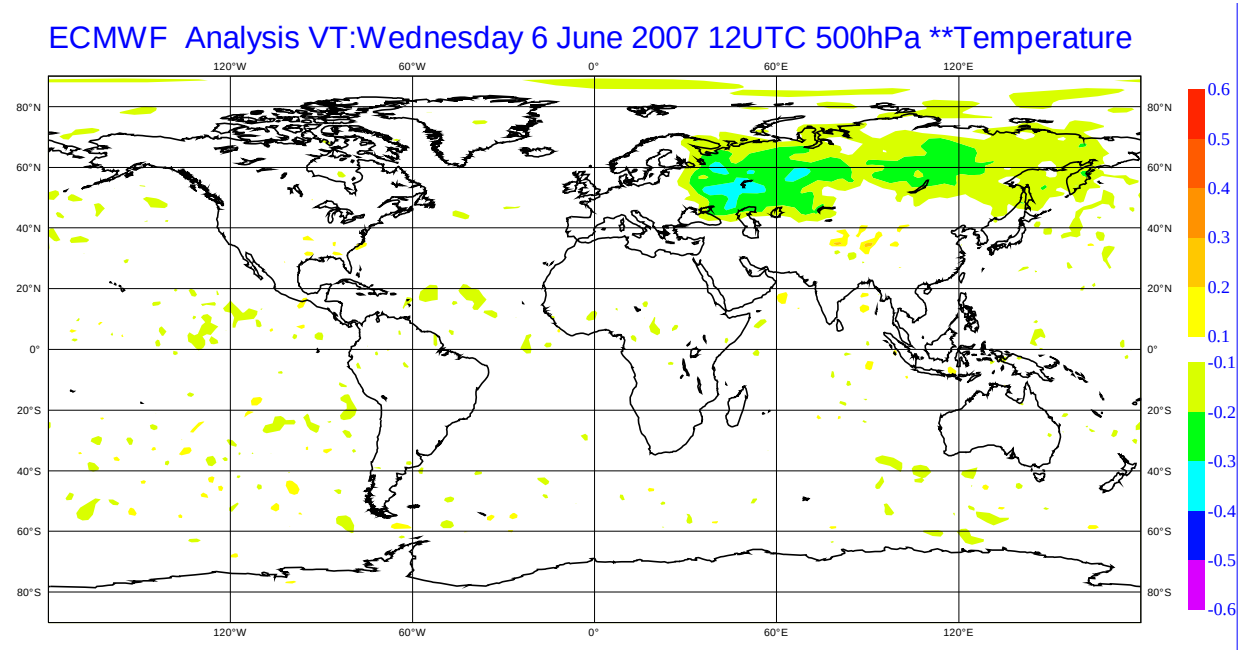
- Development of a new surface analysis scheme (primarily driven by SMOS and ASCAT soil moisture observations).
- Inclusion of correlated observation errors

Longer-term projects:

- Ensembles of data assimilation to investigate and quantify analysis uncertainty.
  - Will be implemented first in support to EPS
- Development of advanced diagnostic tools to understand impact of observations on analysis/forecast.
- Weak-constraint 4D-Var accounting for model error.

New bias correction for radiosondes

- **Addresses the solar radiation effects.**
- **Unifies and automate the bias-correction methods used in reanalysis and operations.**
- **Bias-corrects the humidity for the first time.**
- **The Vaisala RS92 sonde during night-time has been chosen as the reference to which the bias-correction is drawing.**



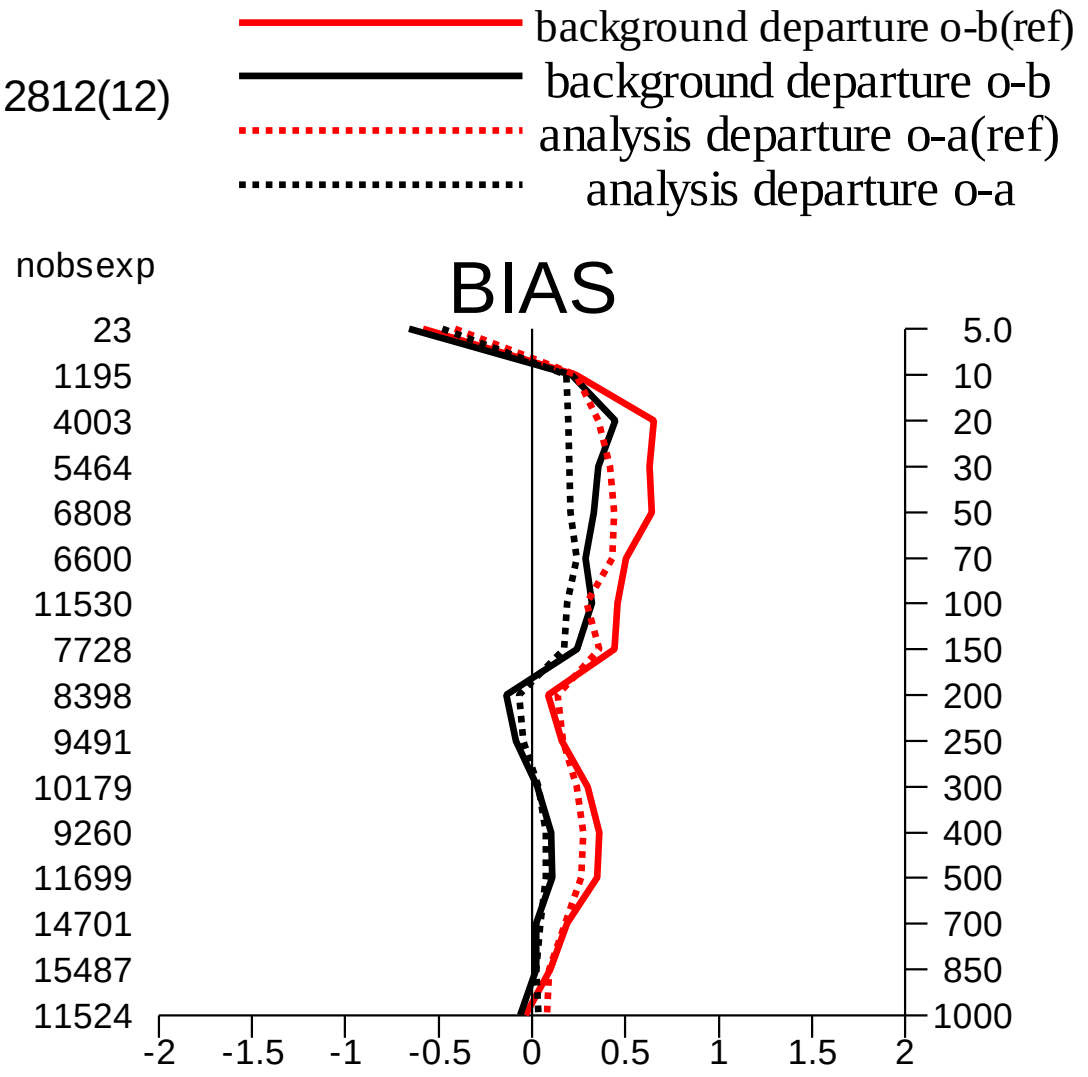
Main T-bias impact in the troposphere is due to the Russian AVK sonde.

Main q-bias impact is a widespread moistening in lower troposphere by ~2%.

Radiosonde bias corrections

Russian-AVK equipment
Temperature
February 2007

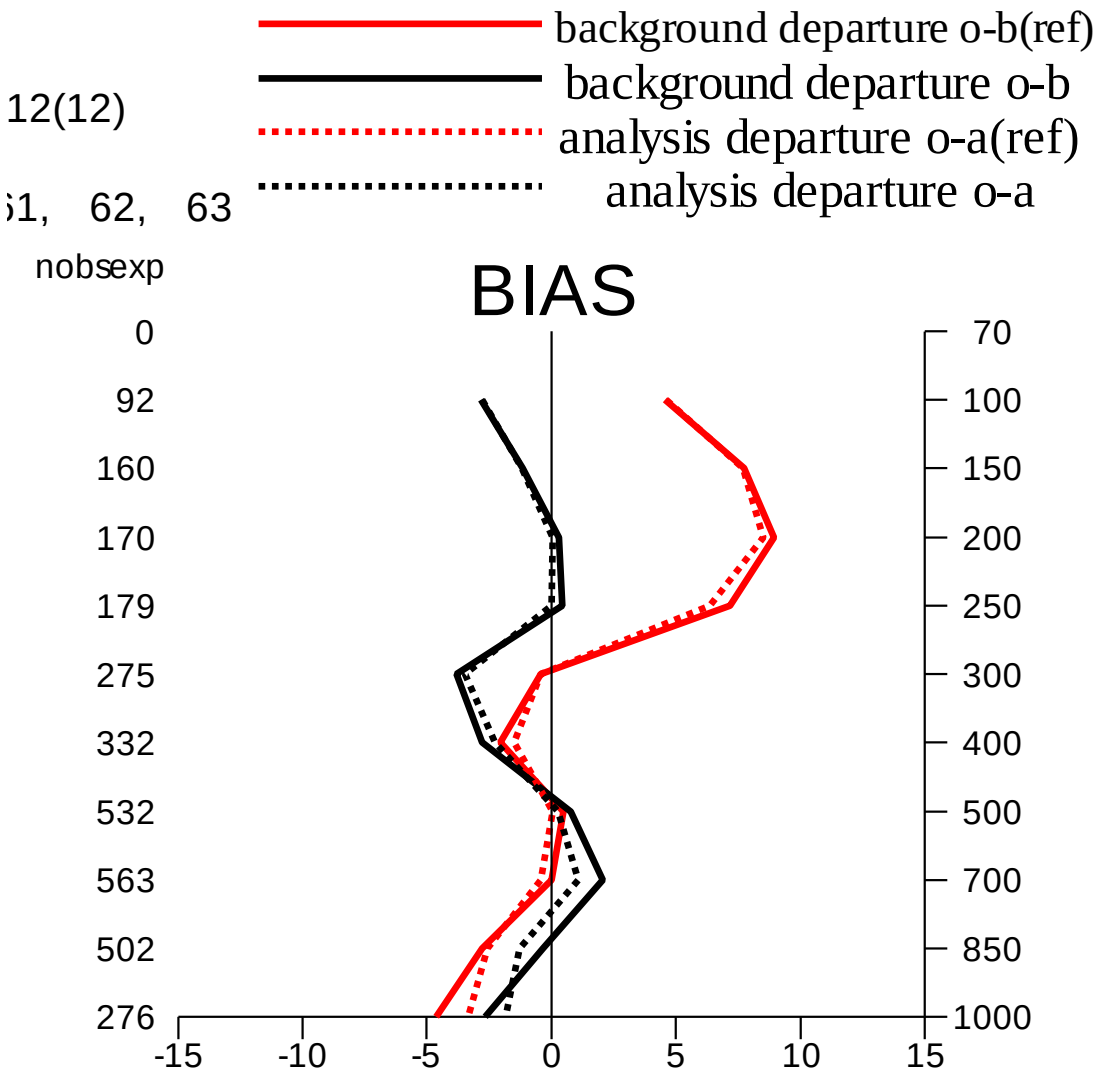
New vs.
operational



Radiosonde bias corrections

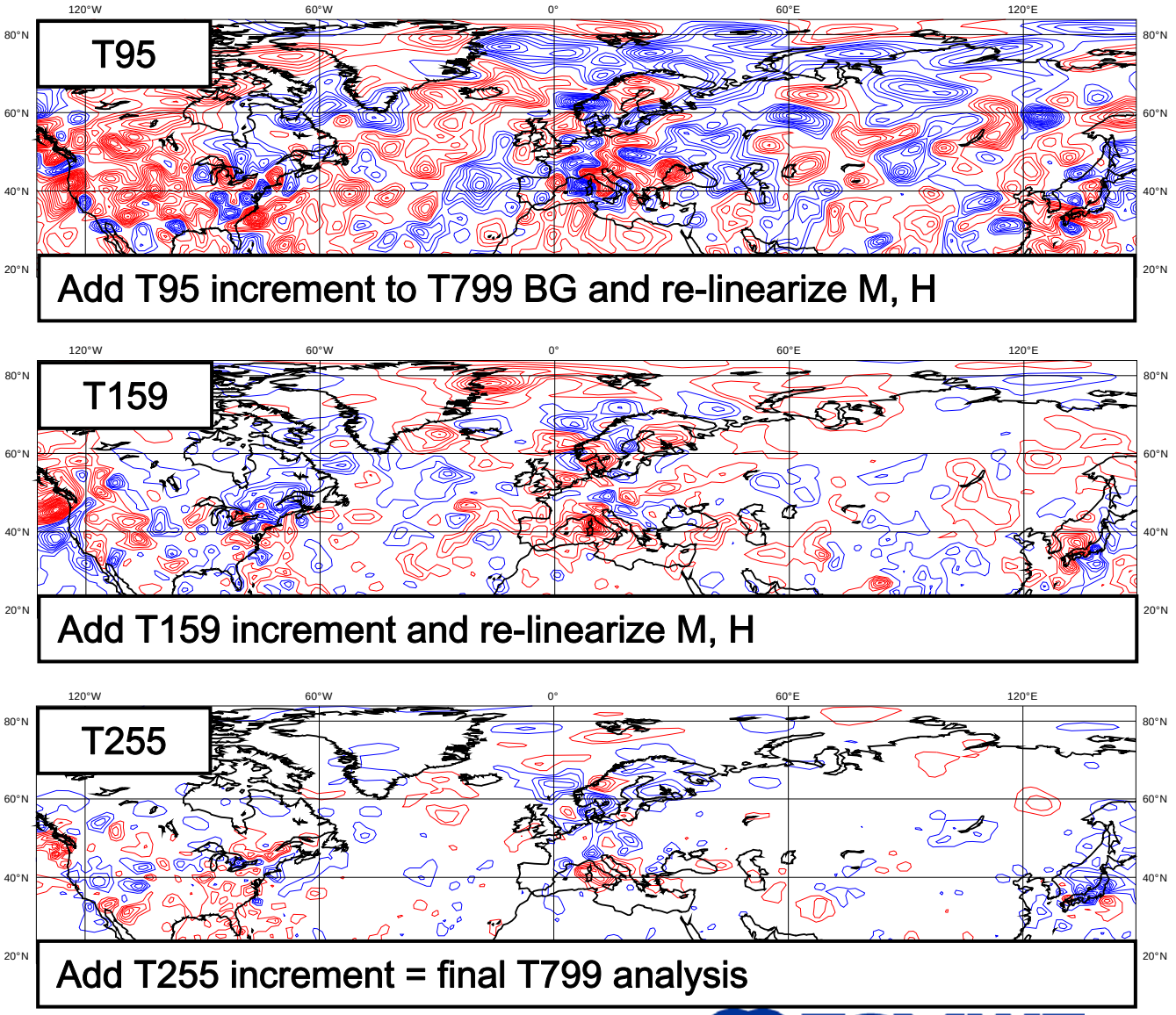
Vaisala-RS80
equipment
Humidity
February 2007

New vs.
operational



4D-Var with three outer loop: efficient, accurate and allows non-linearity

- ML=80 (900 hPa) temp. analysis increments for each of the three minimizations.
- Decreasing amplitudes T95>T159>T255.
- Small corrections added at T255 where data density is highest.
- Model and obs. operators are re-linearized twice.



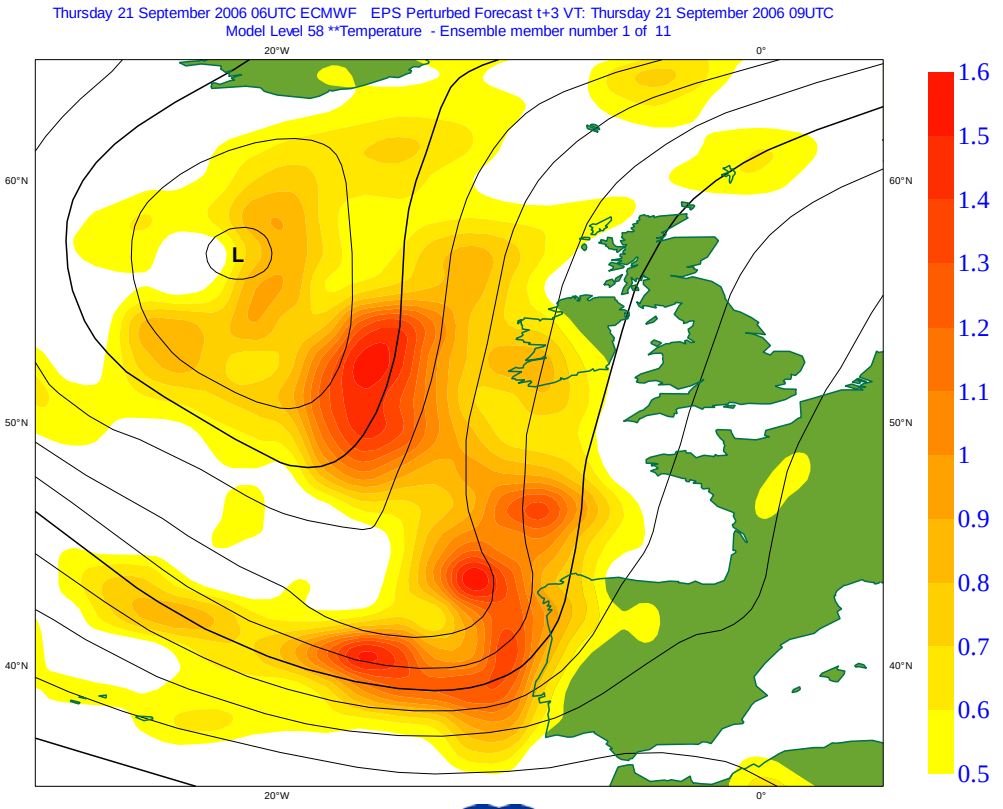
ECMWF

Ensembles of data assimilations

- **Run an ensemble of analyses with random observation, SST and model perturbations and , and form differences between pairs of analyses (and forecast) fields.**
- **These differences will have the statistical characteristics of analysis (and forecast) error.**

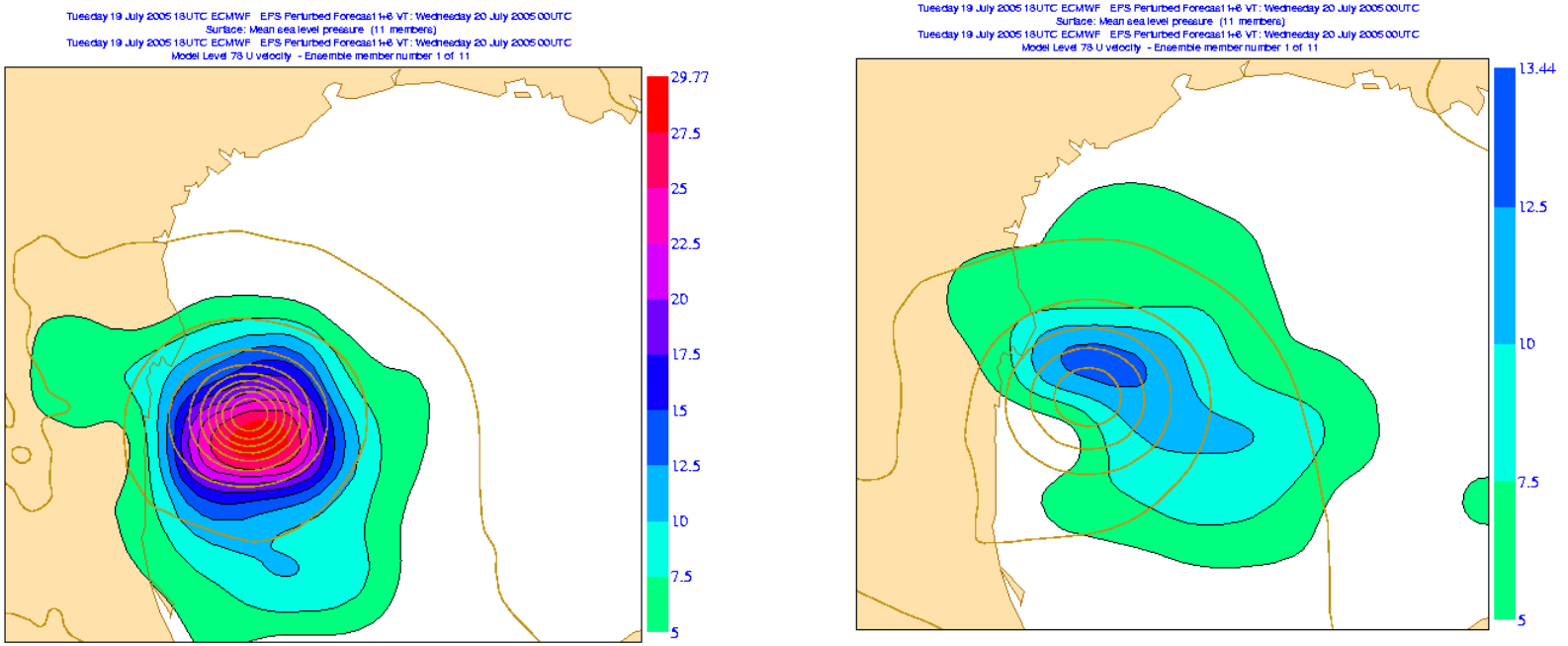
To be used in specification of background errors = "errors of the day". To indicate where good data should be trusted in the analysis (yellow shading).

Also for initialization of the EPS



Impact of the resolution of the analysis ensemble

- **An affordable EnDA system has been designed for operational use at ECMWF (T399 (T159 inner loop))**
  - **Performs well on average**
- **Experiments suggest that much higher resolution is needed in case of extreme events (trials at T799 (T95/T255 inner loops))**

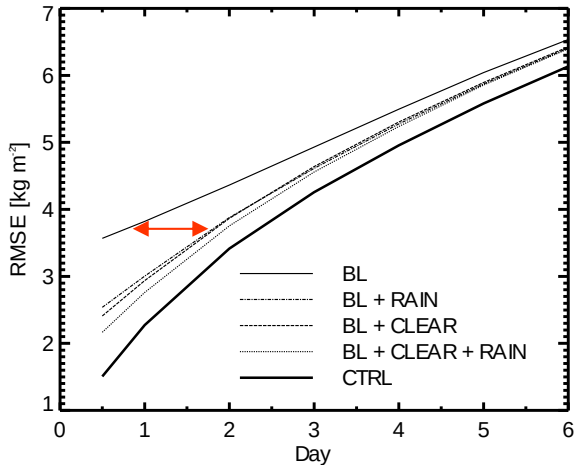


Tropical cyclone Emily: STDEV of 850 hPa zonal wind from 10 member EnDA (T799: left panel, T399: right panel) ensembles

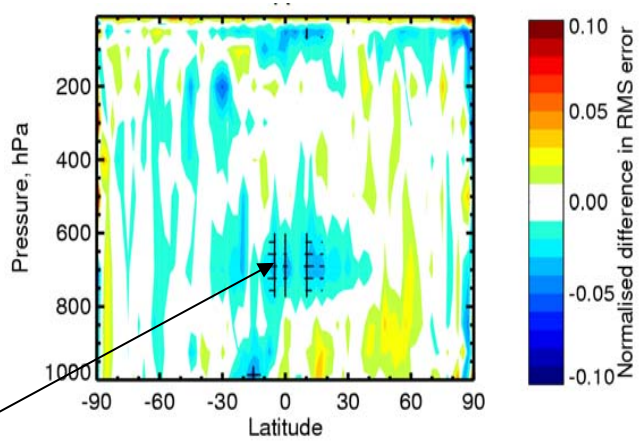
Advanced diagnostics

➢ Example: Assimilation of rain-affected SSM/I observations:

OSE TCWV forecast skill

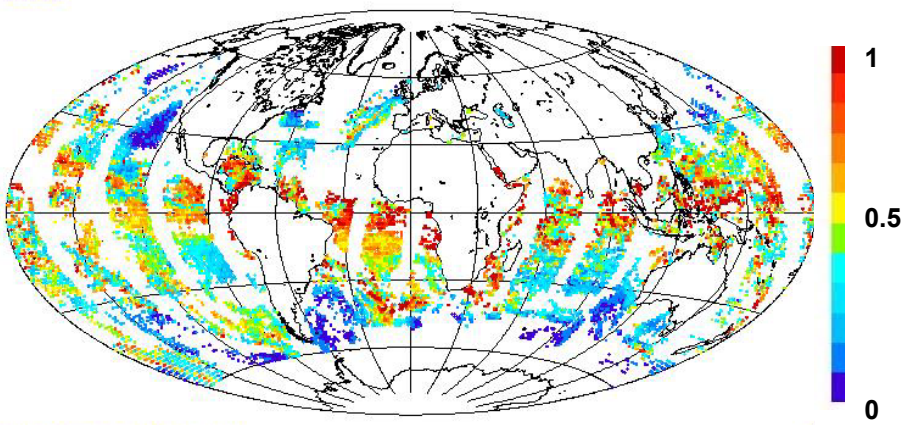


T+48h RAIN – NORAIN impact on relative humidity

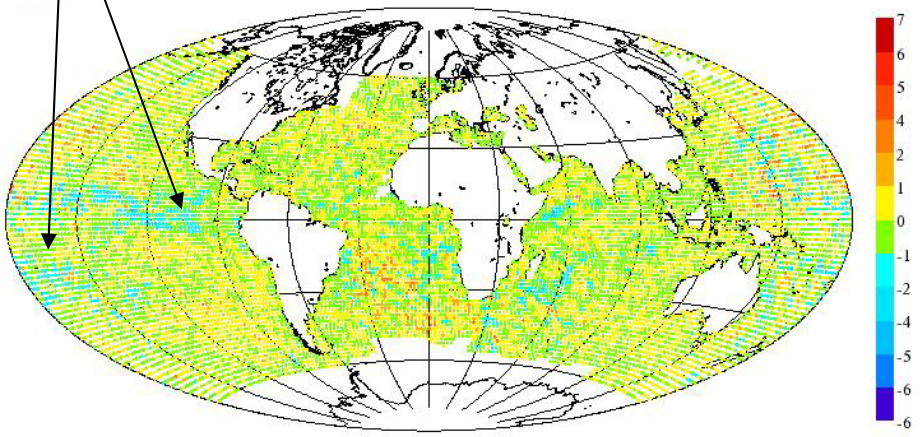


Improvement

Influence of TCWV observations in the analysis

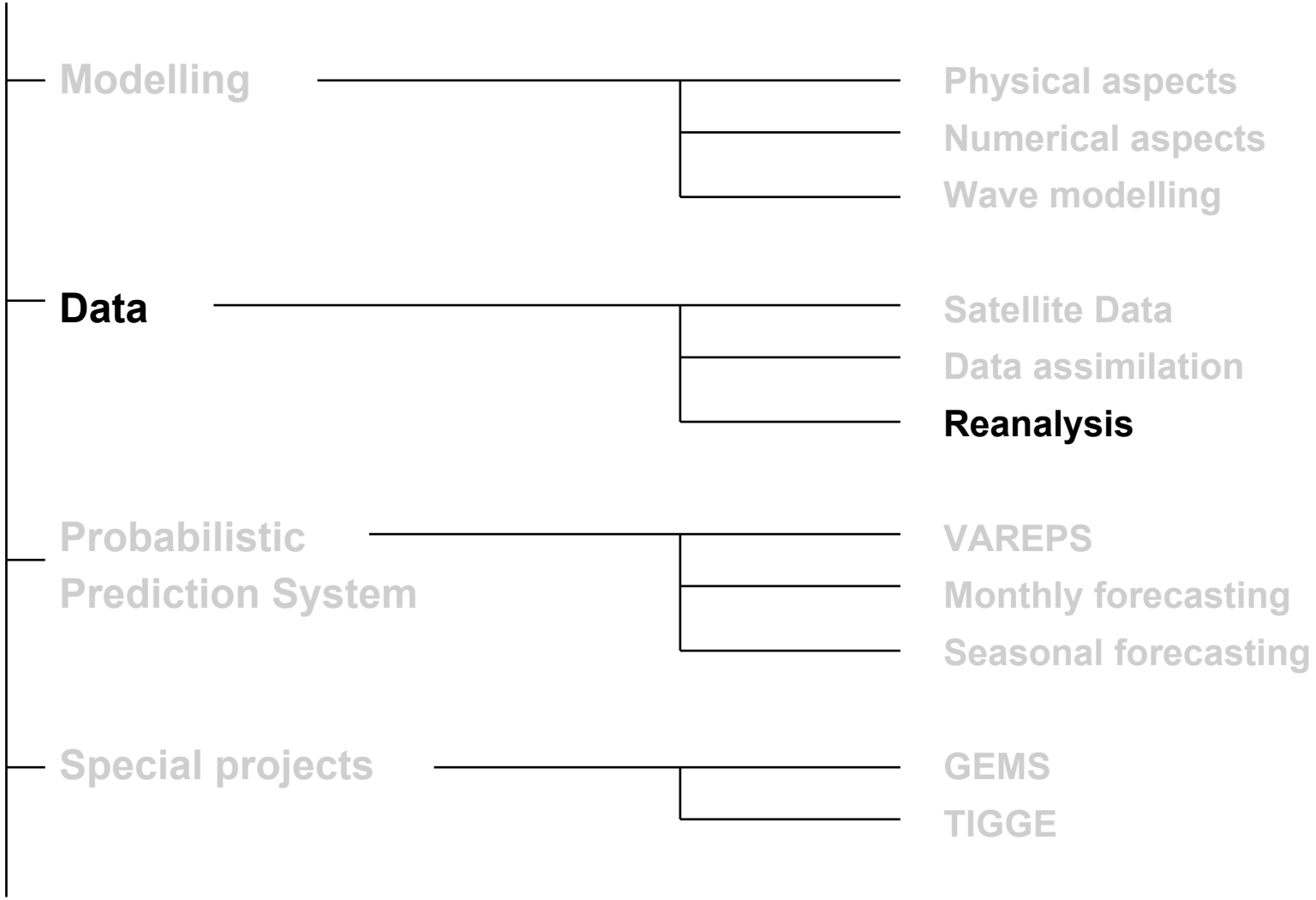


Forecast sensitivity to TCWV observations



[J/kg]

Introduction



Outlook

Reanalysis

- ERA-Interim is based on CY31R2, 12 hour 4D-Var, model T255L60.
- Started in August 2006 running period beginning in 1989.
- Now reached mid 2005, real-time will be reached by the end of 2008.
- ERA-Interim will continue as Climate Data Assimilation System, subject to funding.
- Several aspects in the analysis quality indicate significant improvements over ERA-40.
- Variational Bias Correction (VarBC) behaves very well.

- A larger project (ERA-75) is being built to be proposed for funding by EU (FP7).

Variational bias correction:
The modified analysis problem

The original problem:

J_b: background constraint

$$J(\mathbf{x}) = (\mathbf{x}_b - \mathbf{x})^T \mathbf{B}^{-1} (\mathbf{x}_b - \mathbf{x}) + [\mathbf{y} - \mathbf{h}(\mathbf{x})]^T \mathbf{R}^{-1} [\mathbf{y} - \mathbf{h}(\mathbf{x})]$$

J_o: observation constraint

The modified problem:

J_b: background constraint for x

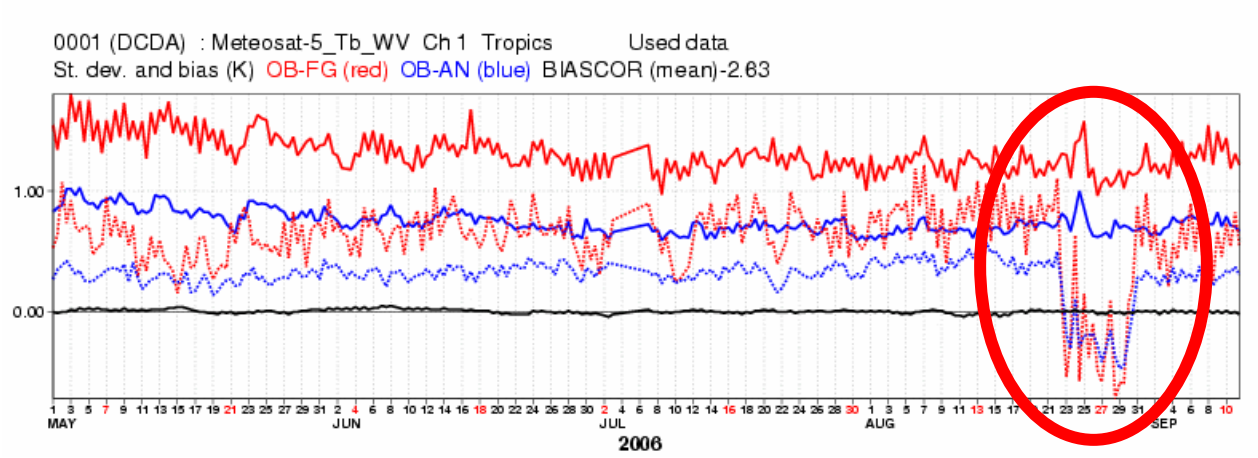
J_β: background constraint for β

$$J(\mathbf{x}, \boldsymbol{\beta}) = (\mathbf{x}_b - \mathbf{x})^T \mathbf{B}_x^{-1} (\mathbf{x}_b - \mathbf{x}) + (\boldsymbol{\beta}_b - \boldsymbol{\beta})^T \mathbf{B}_\beta^{-1} (\boldsymbol{\beta}_b - \boldsymbol{\beta}) + [\mathbf{y} - \mathbf{b}_o(\mathbf{x}, \boldsymbol{\beta}) - \mathbf{h}(\mathbf{x})]^T \mathbf{R}^{-1} [\mathbf{y} - \mathbf{b}_o(\mathbf{x}, \boldsymbol{\beta}) - \mathbf{h}(\mathbf{x})]$$

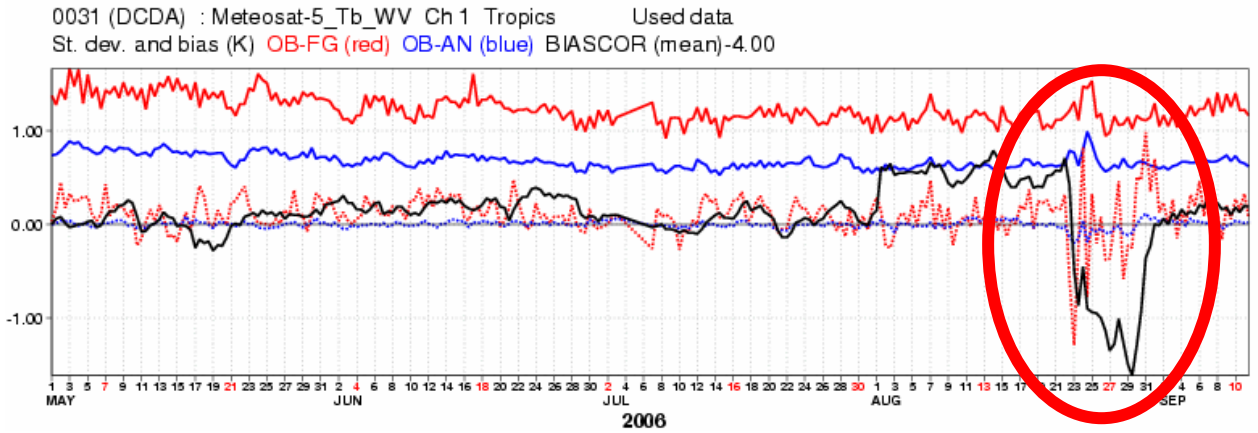
Parameter estimate from previous analysis

J_o: bias-corrected observation constraint

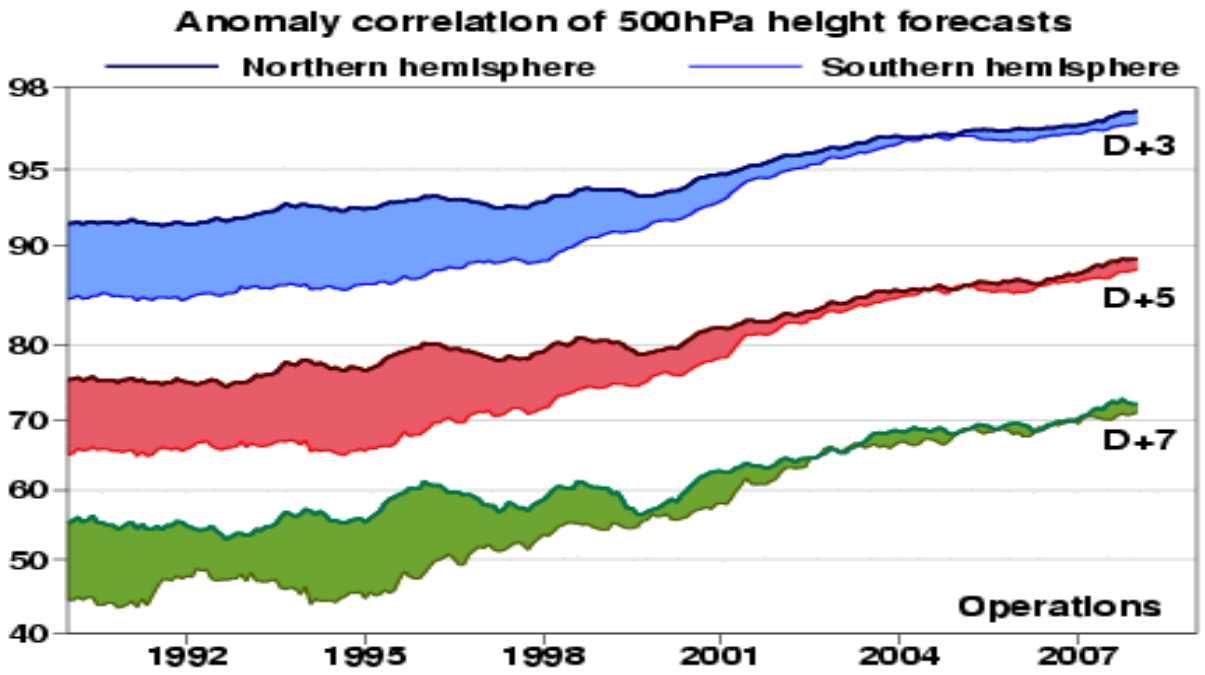
Impact of adaptive bias correction: VARBC (shock absorber when there is a problem with the data)



Standard BC



VARBC


Anomaly correlation of 500hPa height forecasts
Northern hemisphere
Southern hemisphere
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95
90
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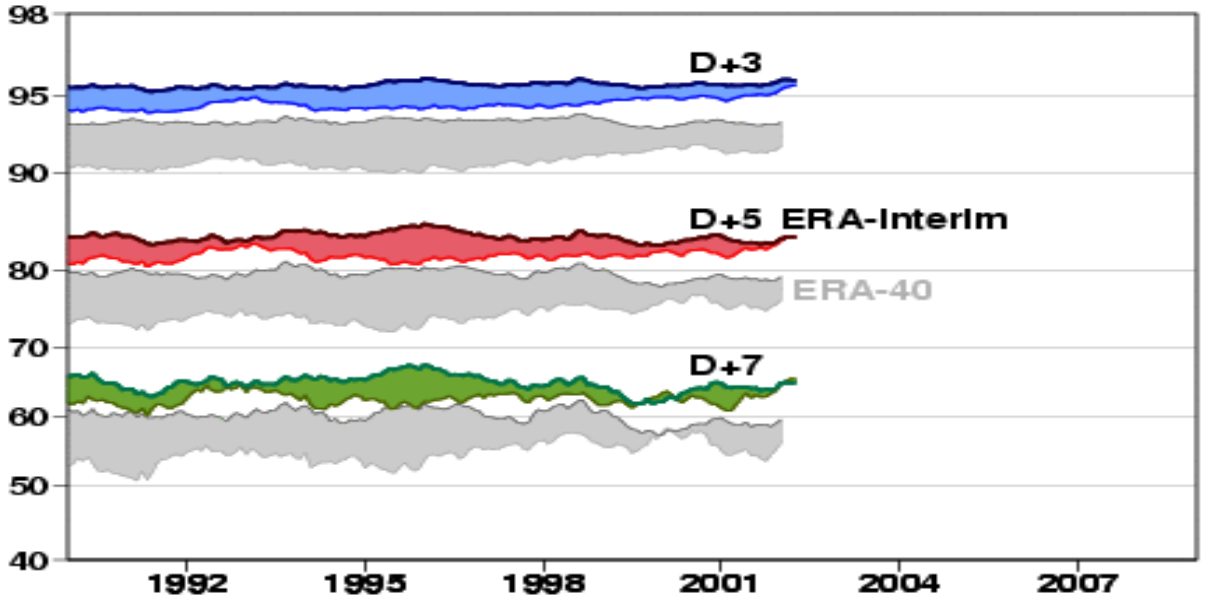
70
60
50
40
D+3
D+5
D+7
Operations
1992
1995
1998
2001
2004
2007


98
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90
80
70
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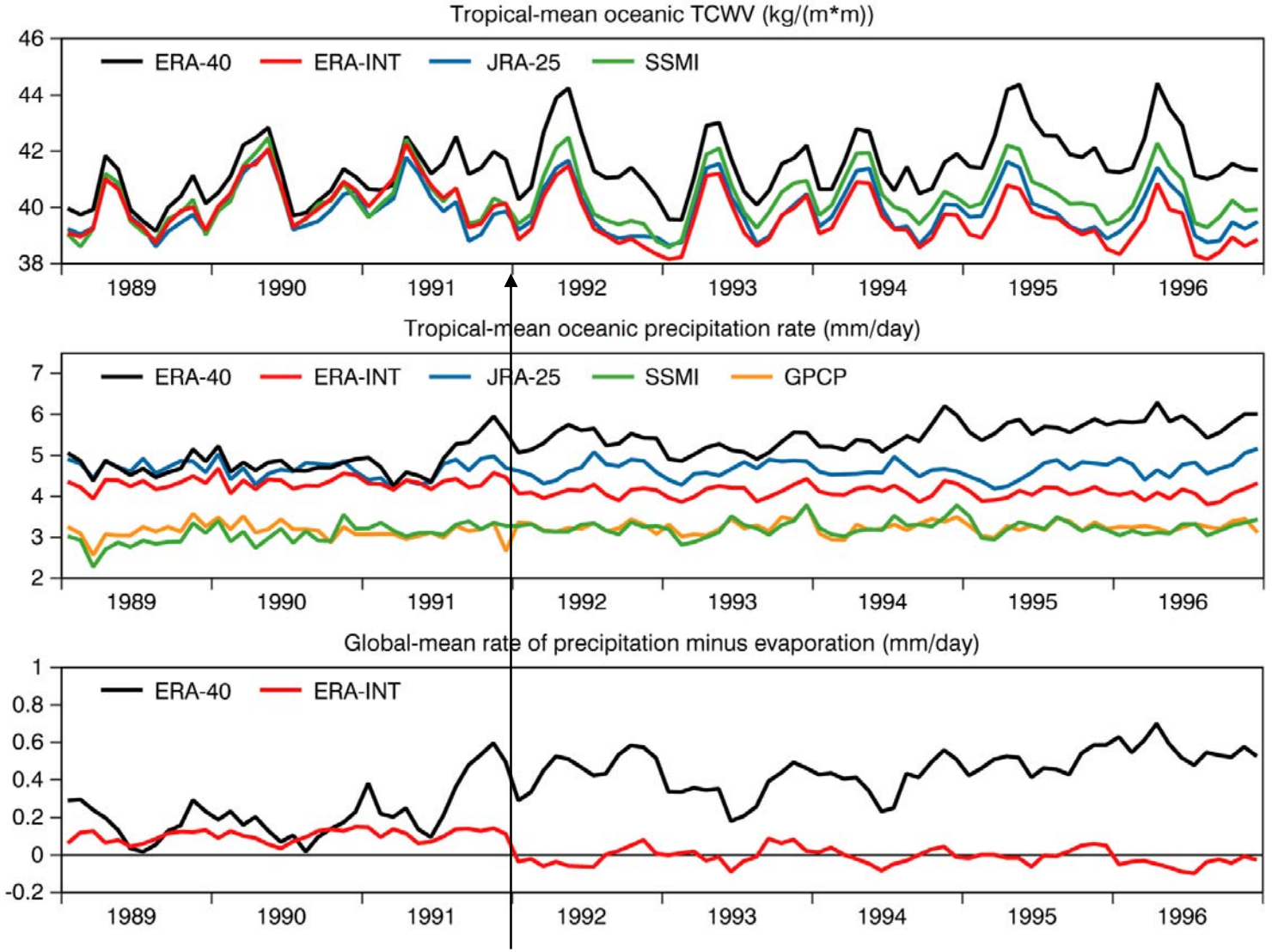
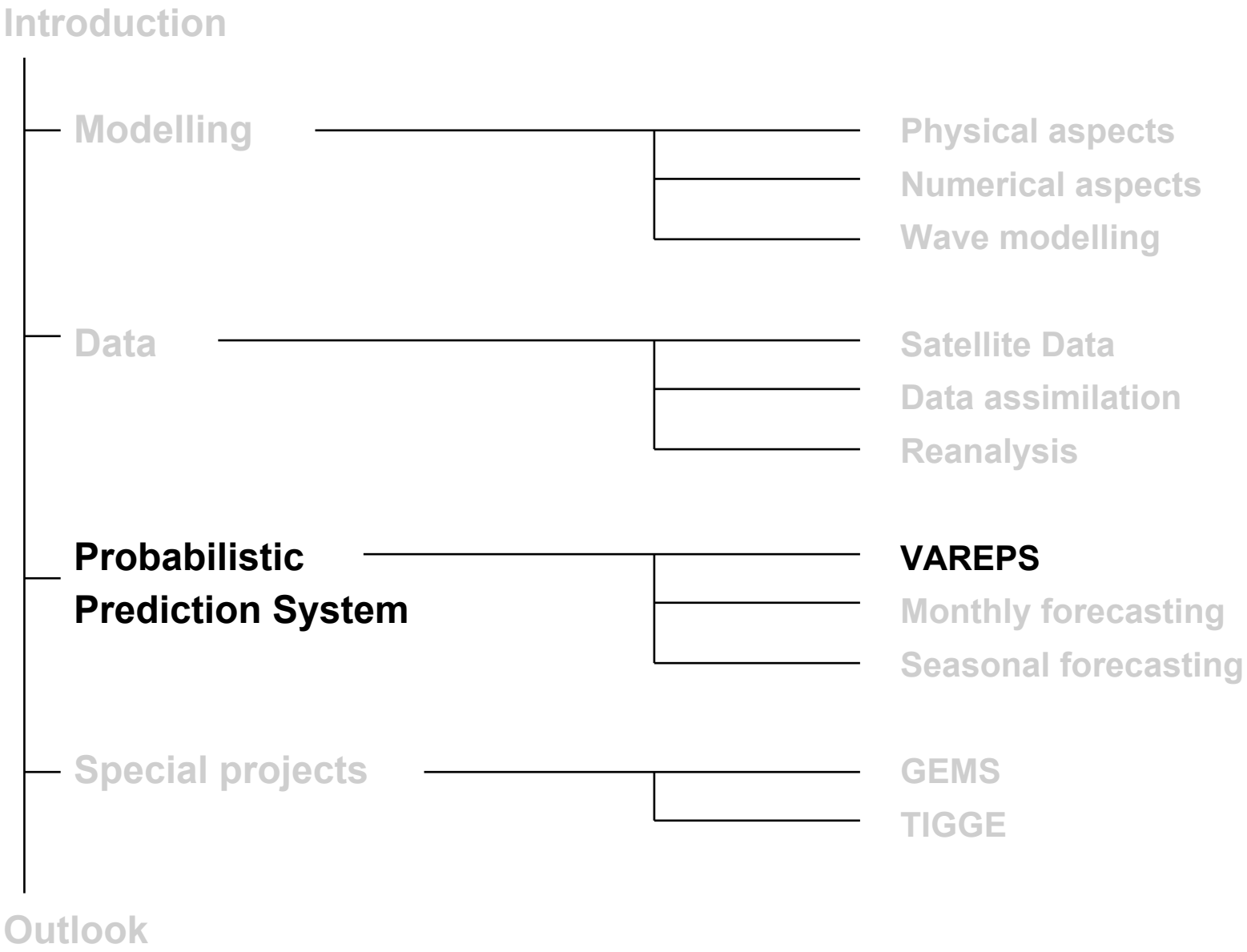
D+3
D+5 ERA-Interim
ERA-40
D+7
1992
1995
1998
2001
2004
2007

Improved hydrological balance



Mt. Pinatubo eruption and NOAA-12 active (w/ flawed bias correction)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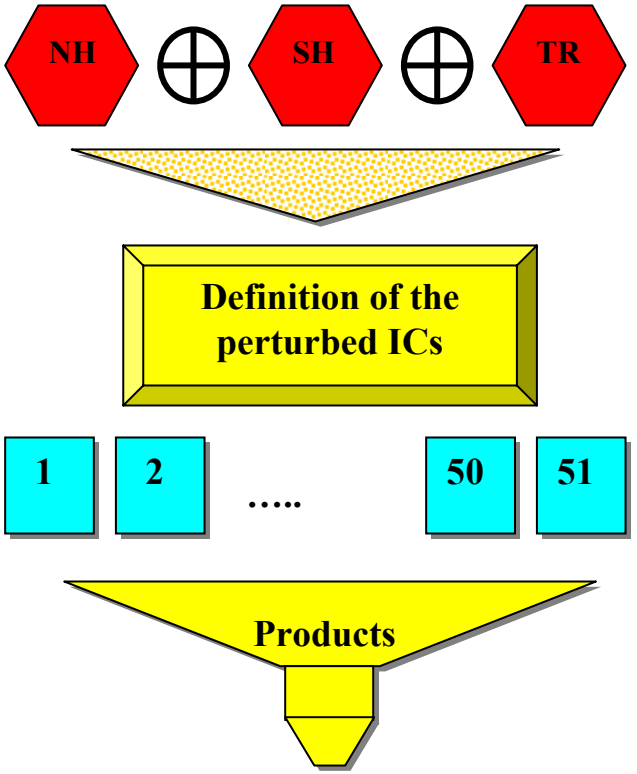
The 15-day VAREPS

The Ensemble Prediction System consists of 51 forecasts run with variable resolution:

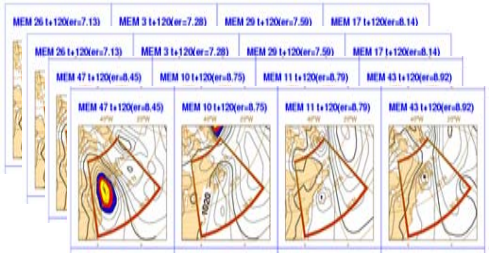
- T_L399L62 (~60km, 62 levels) from day 0 to 10
- T_L255L62 (~80km, 62 levels) from day 10 to 15.

The EPS is run twice a-day, at 00 and 12 UTC.



Initial uncertainties are simulated by perturbing the unperturbed analyses with a combination of T42L62 singular vectors, computed to optimize total energy growth over a 48h time interval (OTI).

Model uncertainties are simulated by adding stochastic perturbations to the tendencies due to parameterized physical processes.

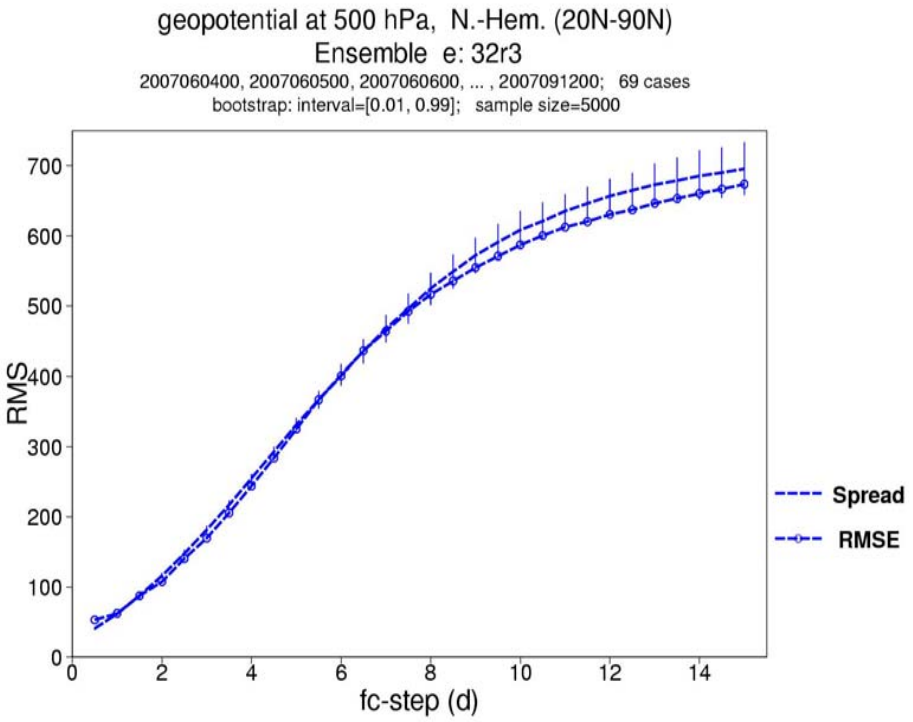


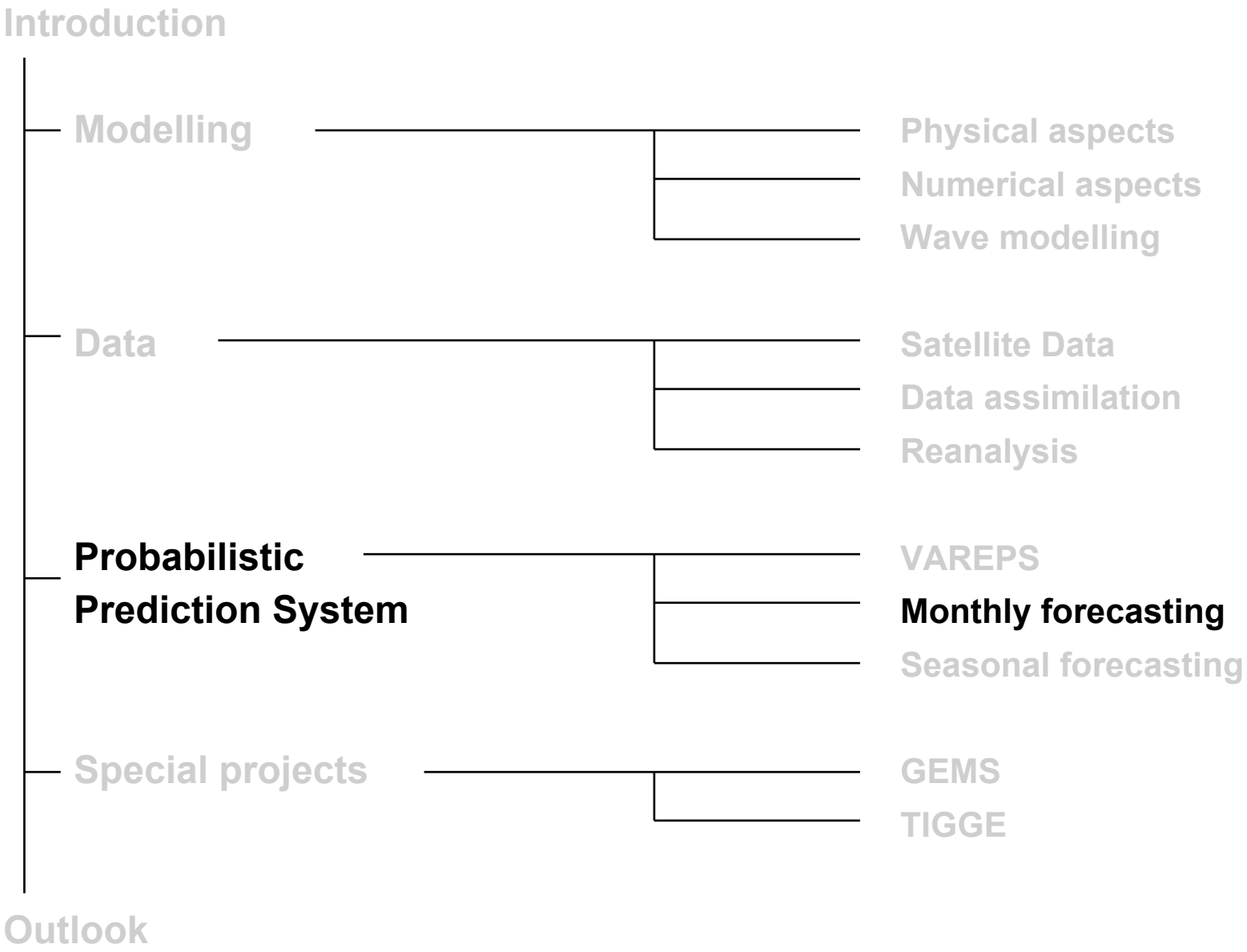
ECMWF

The VAriable Resolution EPS (VAREPS)

- The key idea behind VAREPS is to resolve small-scales only up to the time range when resolving them improves the forecast. VAREPS was implemented in September 2006 with the following configuration.

- VAREPS has increased the value of the ensemble system in the short range, by providing more skilful predictions of the small scales, and in the medium-range, by extending the range of skilful products to 15 days.
- With the introduction of the new model cycle on 6 Nov 2007 the ensemble has a better tuned spread. Furthermore, between fc-day 3 and 7 the ensemble-mean of the e-suite has a significantly smaller error.

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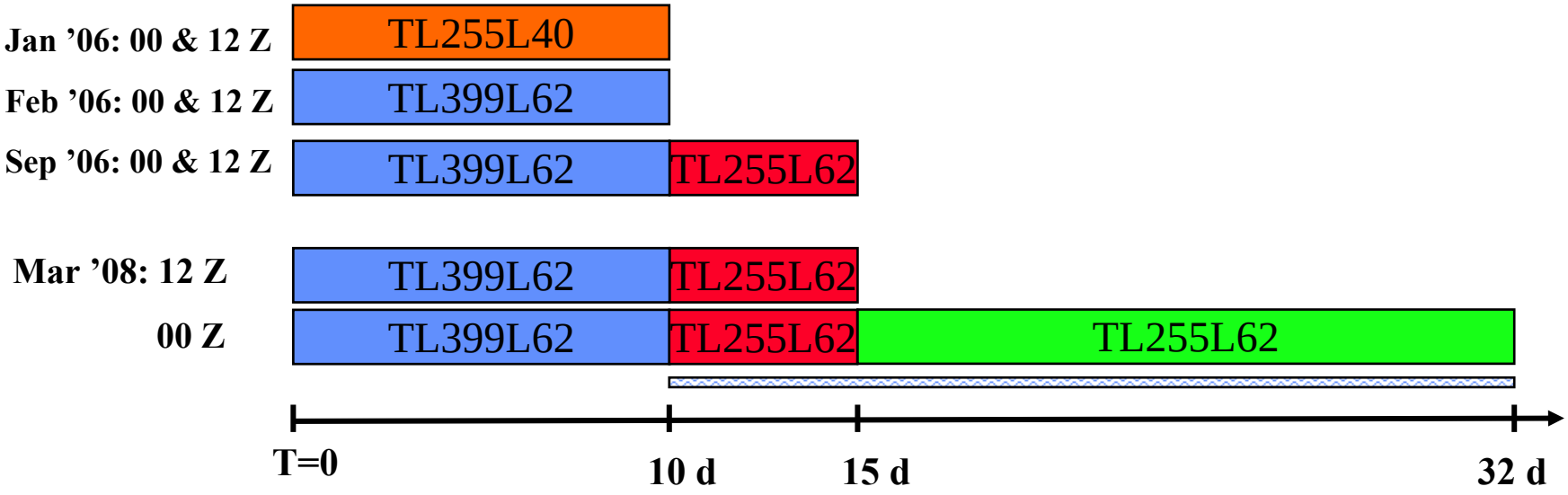
The 2008 seamless VAREPS/monthly ensemble system

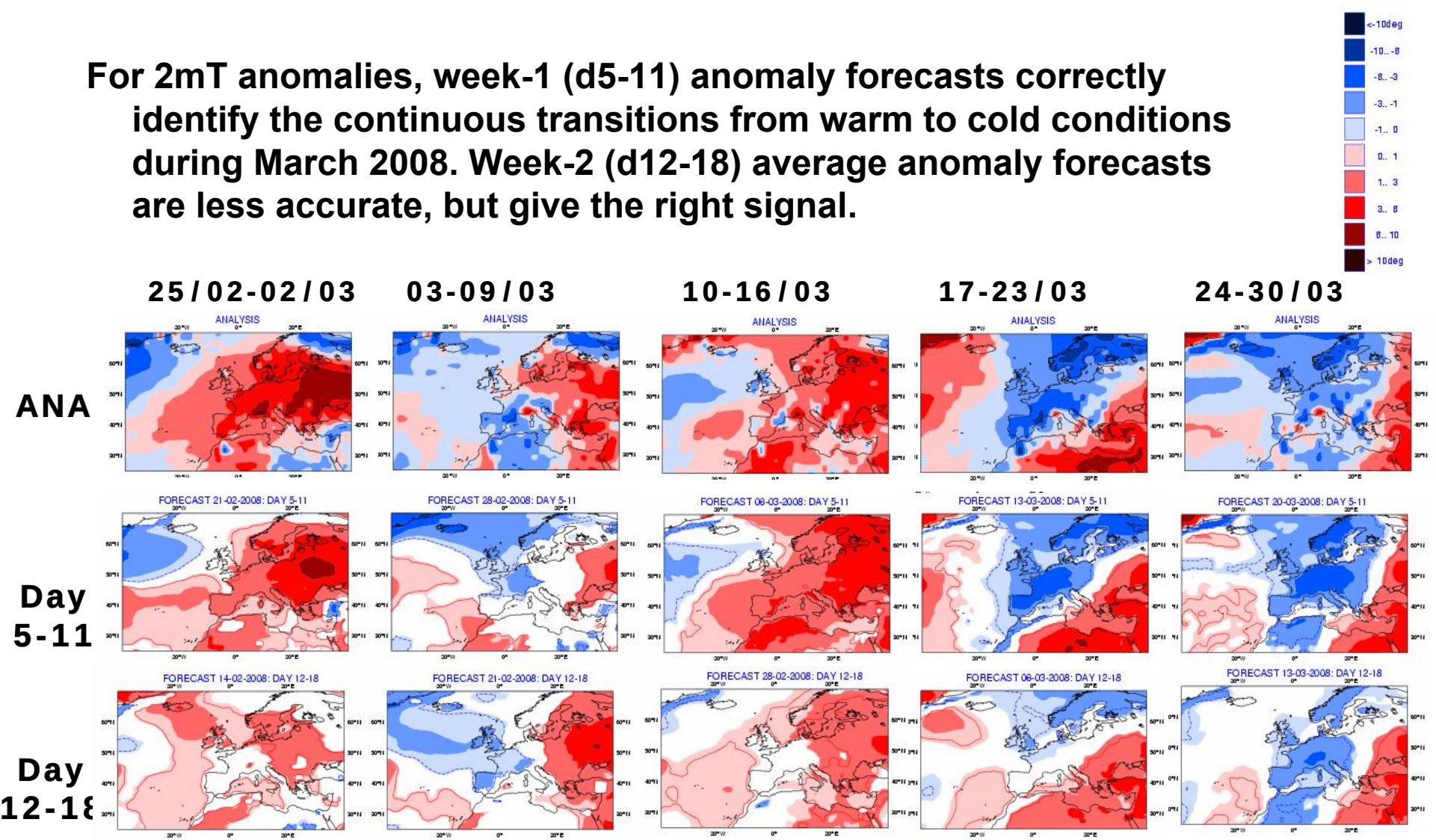
- **Until 1 Feb '06, the EPS had 51 10-day forecasts at T_L255L40 resolution**
- **On the 1st of Feb '06, the 10-day EPS resolution was upgraded to T_L399L62**
- **On the 12th of Sep '06, the new Variable Resolution EPS (VAREPS) was introduced, and the ensemble forecast range was extended to 15 days**
- **On the 11th of Mar '08 the 15-day VAREPS has been merged with the monthly forecast system: since then the 00 UTC forecasts use a coupled ocean model from day 10**



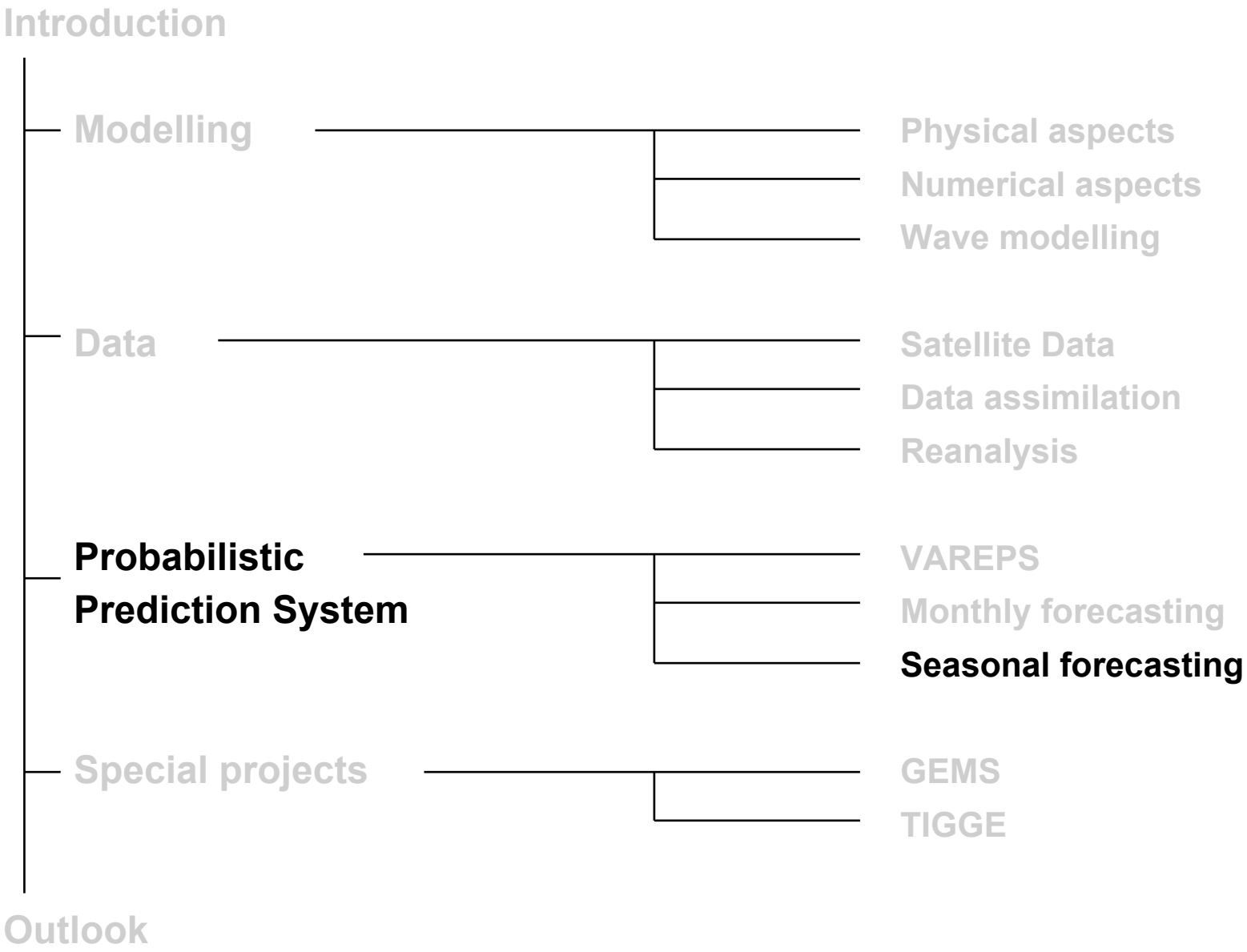
ECMWF

March-April 2008: week-1 and week-2 2mT' fcs

For 2mT anomalies, week-1 (d5-11) anomaly forecasts correctly identify the continuous transitions from warm to cold conditions during March 2008. Week-2 (d12-18) average anomaly forecasts are less accurate, but give the right signal.



ECMWF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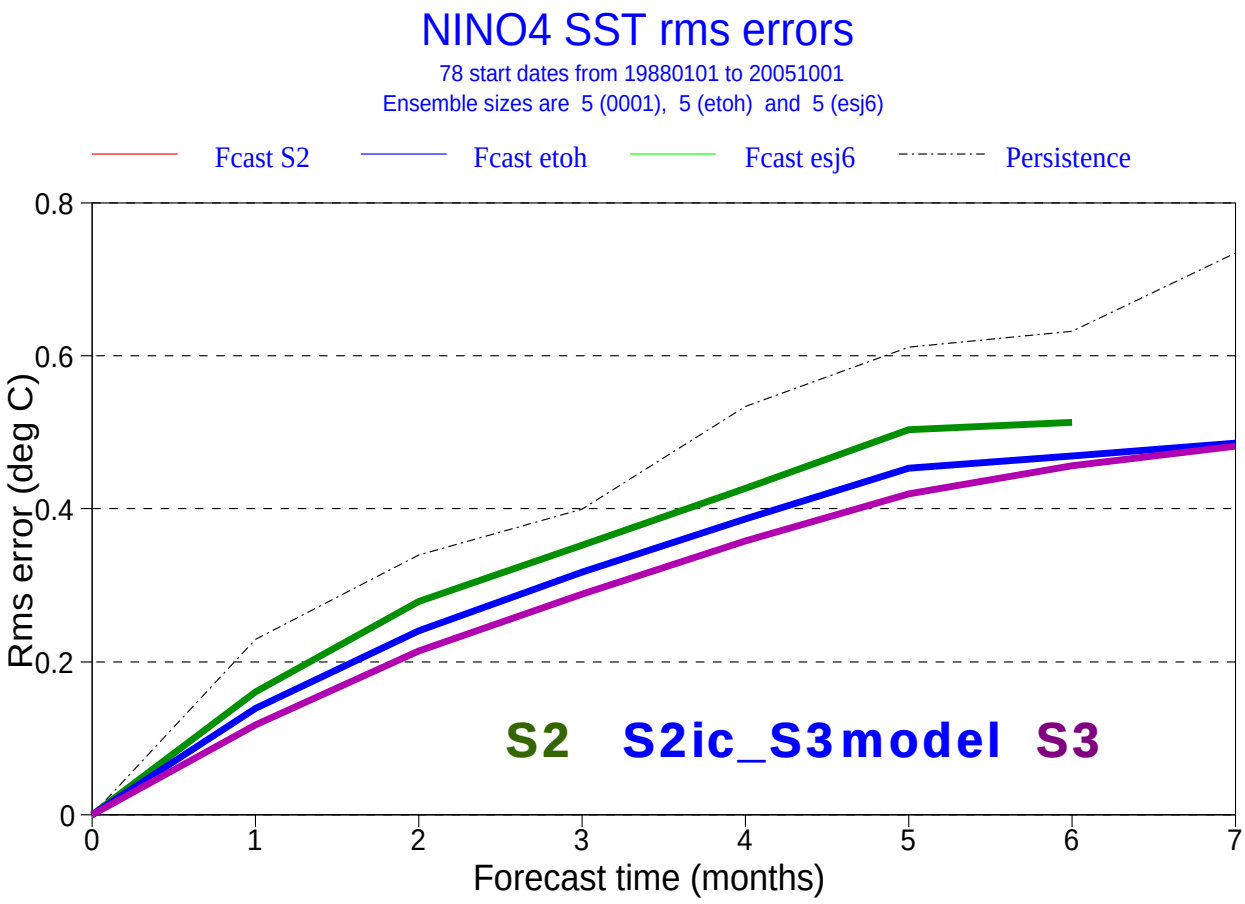
The seasonal System-3

- Coupled model (IFS + OASIS2 + HOPE)
  - Recent cycle of atmospheric model (Cy31R1).
  - Atmospheric resolution TL159 and 62 levels.
  - Time varying greenhouse gasses.
  - Includes ocean currents in wave model.
- Initialization
  - Includes bias correction in ocean assimilation.
  - Includes assimilation of salinity and altimeter data.
  - ERA-40 data used to initialize ocean and atmosphere in hindcasts.
  - Ocean reanalysis back to 1959, using ENACT/ENSEMBLES ocean data.
- Ensemble generation
  - 41 ensemble members
  - 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 (and to 13 months 4 times per year).

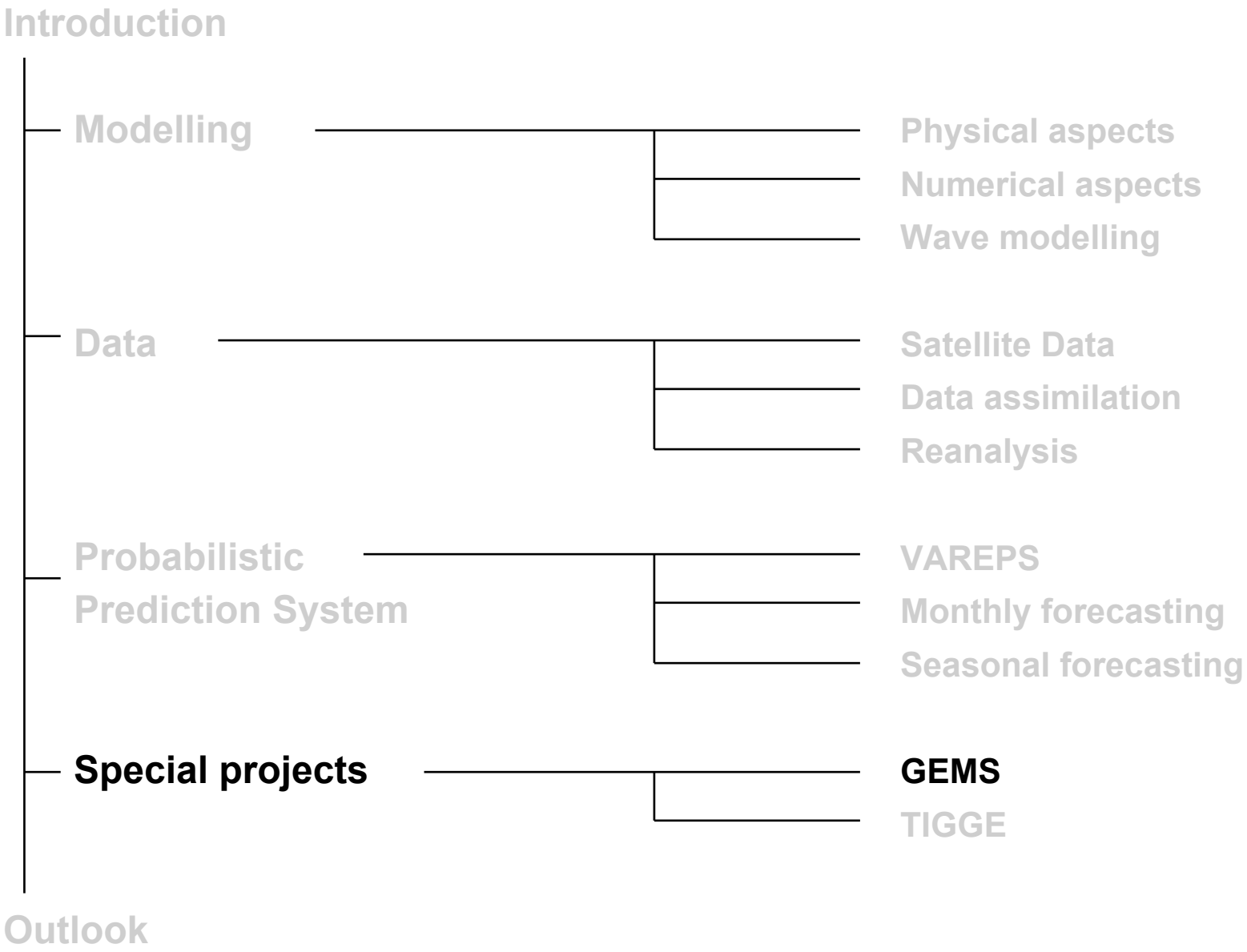
The seasonal System-3

- System-3 is operational since March 2007.
- System-3 forecast skill improvement comes equally from better model and better ocean DA.
- Several new products are now generated (climagrams, tercile summaries, tropical storms, etc…).



Development of System-4 (NEMO and NEMOVAR)

- Collaboration with CERFACS, INRIA, MERCATOR.
- Good progress on general infrastructure, for operational and research coupled runs, and DA using both 3D-Var and 4D-Var options.
- Use OASIS-3 (waiting for OASIS-4 full functionalities).
- Built on ideas/codes/heritage from:
  - OPAVAR (previous version used at CERFACS),
  - IFS 4D-Var,
  - MERSEA high-resolution coupled IFS-NEMO experiments.
- First coupled runs already made and encouraging.
- First research 3D-Var experiments expected by end 2007.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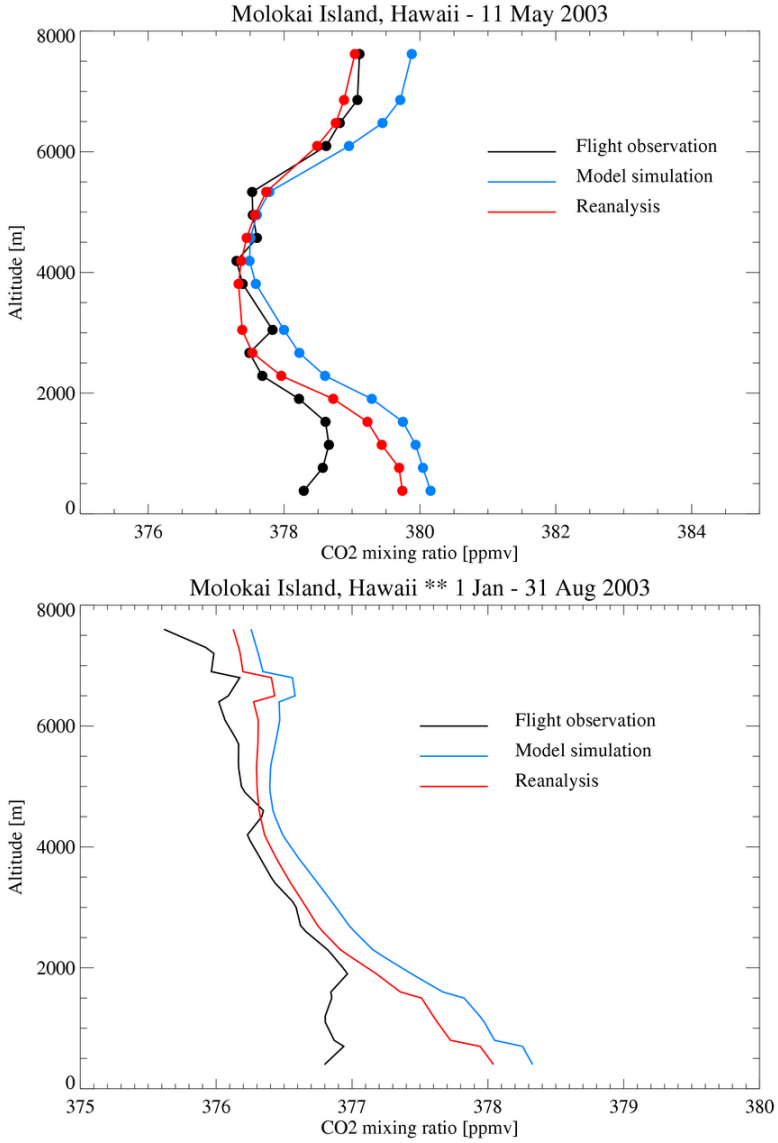
GEMS tasks at ECMWF

- Coordinate the project: 31 partners, 9 of which are Met.services from ECMWF Member and Co-operating states.
- Greenhouse gases:
  - Start on CO_2, then CH_4.
  - Develop modelling and data assimilation, and collaborate with partners in use of analyses to infer sources and sinks for CO_2 and CH_4.
- Reactive gases:
  - Couple main forecast model with global CTMs.
  - Carry O_3, CO, NO_2, SO_2 and HCHO in main model and develop data assimilation.
- Aerosols:
  - Add to model, based on externally-produced parameterizations.
  - Develop assimilation of retrievals, then radiances.
- Integrate above components, and run past periods.
- Acquire data, and provide support for regional air-quality forecasting.

Validation of first extended CO_2 assimilation of AIRS data



Comparisons with flight data over Hawaii (courtesy of Pieter Tans, NOAA/ESRL) shows a clear improvement of the analysis over a free-running model.

The top plot shows a best-case individual comparison (11 May 2003).

The bottom plot shows an average over all available flight profiles between 1 January and 31 August 2003.

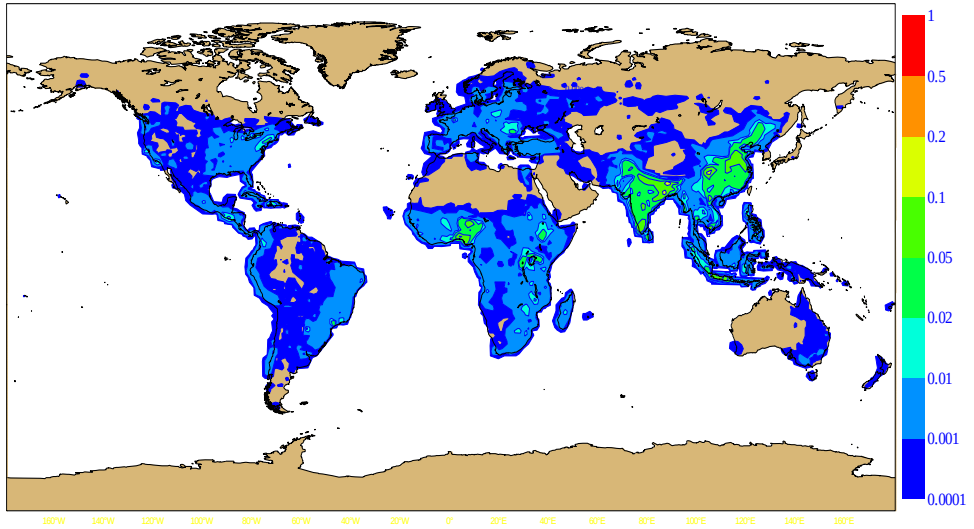
Aerosol model development

Model includes:

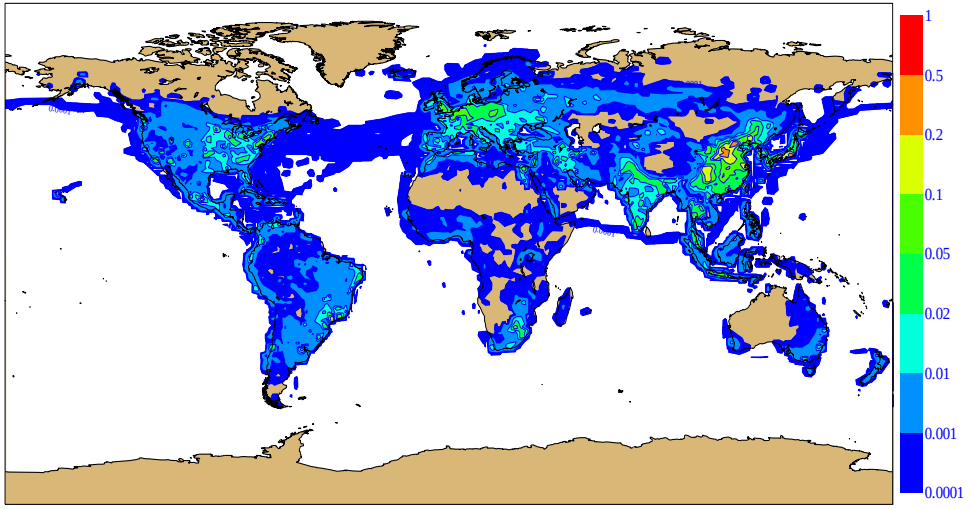
- Sea salt (3 bins, with parameterized source).
- Desert dust (3 bins, with parameterized source).
- Black carbon and organic matter (specified sources).
- Sulphate aerosol (with specified emissions).
- Separate scheme for stratospheric aerosols.

Development (validation, improved modelling and emissions) is ongoing

Black carbon: biogenic source

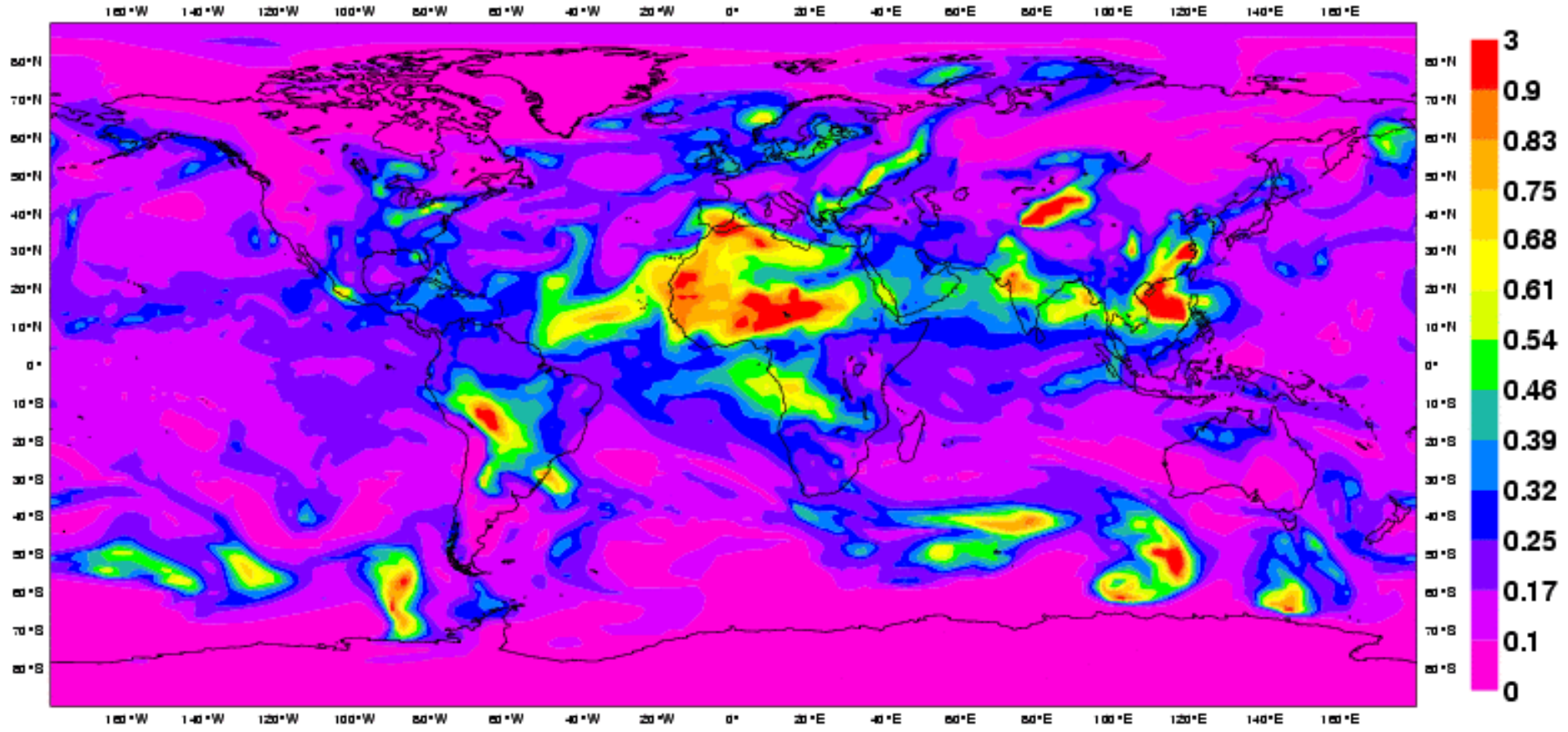


Black carbon: fossil-fuel source



ECMWF

Aerosol forecasts (no assimilation)



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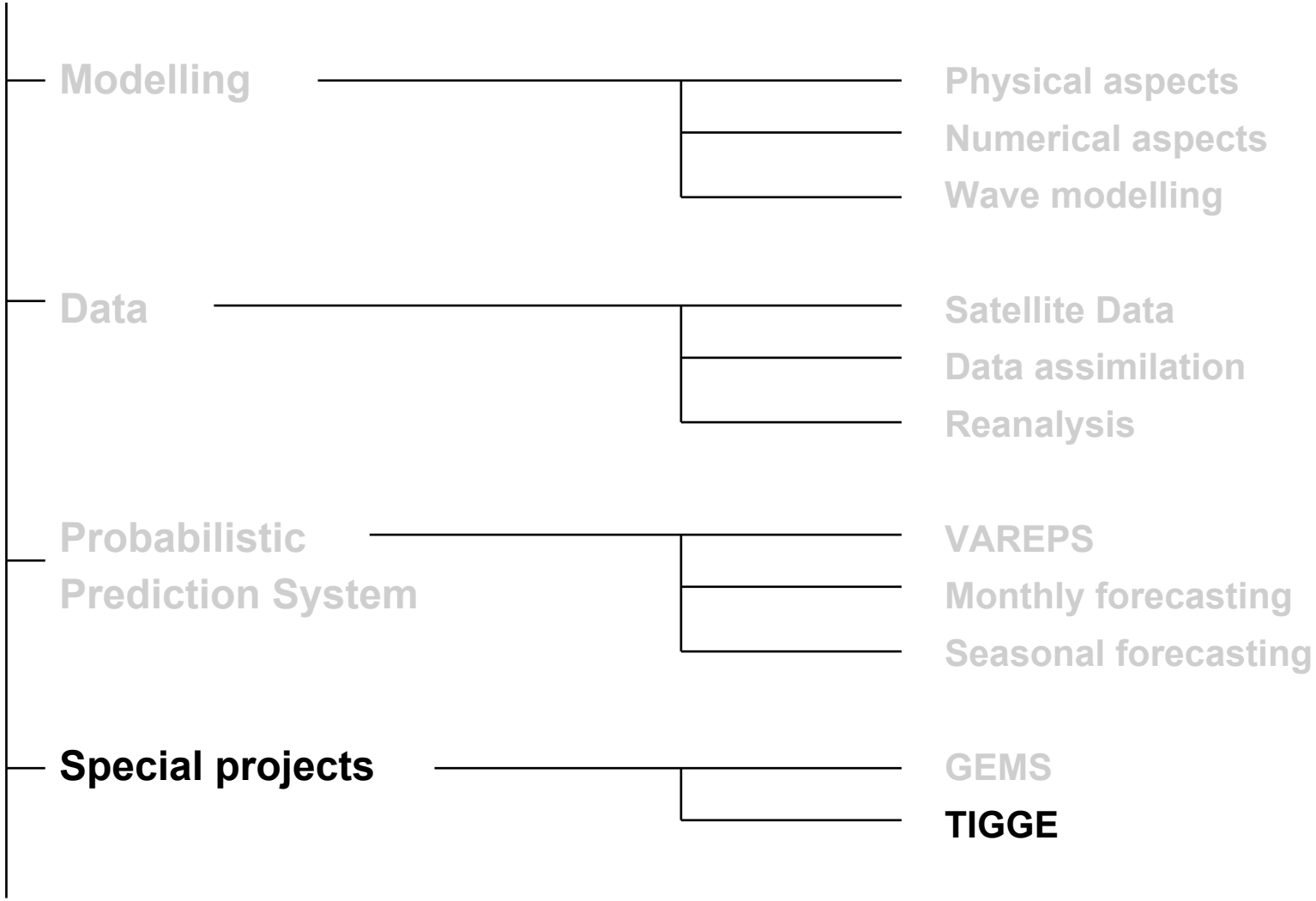


Outlook

ECMWF

Characteristics of the TIGGE ensembles

- **THORPEX Interactive Grand Global Ensemble (TIGGE) will enable enhanced collaboration on development of ensemble prediction, internationally and between operational centres and universities. To achieve this, global ensemble forecast model output will be collected in near real-time, including those from operational centres and made available to researchers in the operational and academic communities.**

- **Global ensemble systems available in the TIGGE archive:**

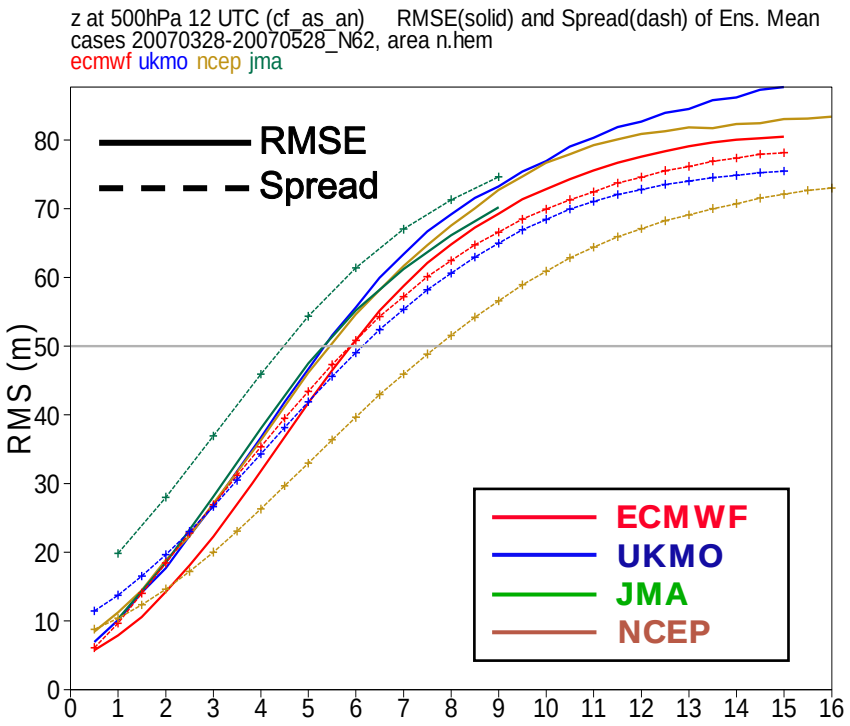
	BMRC	CMA	ECMWF	JMA	KMA	MSC	NCEP	UKMO
Model error	NO	NO	YES	NO	NO	YES	NO	YES
Init perturb	SVi	BVs/SVs	SVi+e	BVs	BVs	Sys-Sim	ET-BVs	ETKF
Perturb area	NH+SH	NH+TR	Globe	NH+TR	NH	NH	Globe	Globe
HRES fcs	TL119	T213	TL399(d0-10) TL255(d10-15)	T106	T213	TL149	T126	N144 (~80km)
# vert-lev	19	31	62	40	40	28	28	38
fc length (d)	10	10	15	9	10	16	16	15
# pert mem	32	14	50	50	16	20	20	23
# runs (d)	2 (00/12)	2 (00/12)	2 (00/12)	1 (12)	2(00/12)	2(00/12)	4 (00/06/ 12/18)	2 (00/12)
# mem (d)	66	30	102	51	34	42	84	48

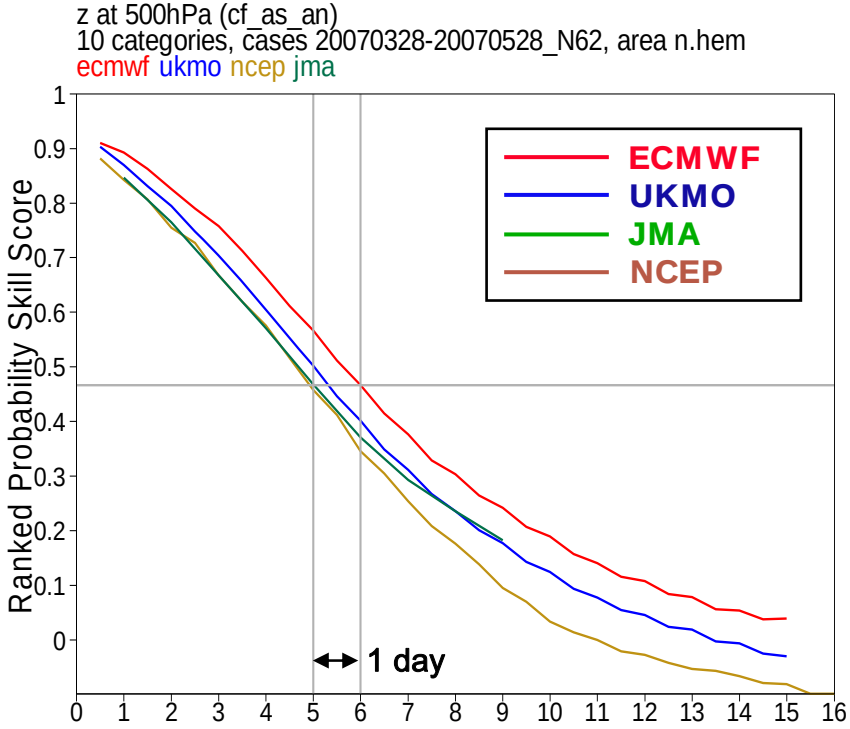
ECMWF

TIGGE: EC/UK/NCEP/JMA ensembles

- Spread (left, dashed): EC best match of std & rmse (EM); UK similar to EC after day 2; JMA too large, NCEP too small.
- RMSE (EM) (left, solid): EC has lowest RMSE for whole forecast range.
- RPSS (right): EC has highest value.

(Evaluation for April-May 2007, verification against own analyses)





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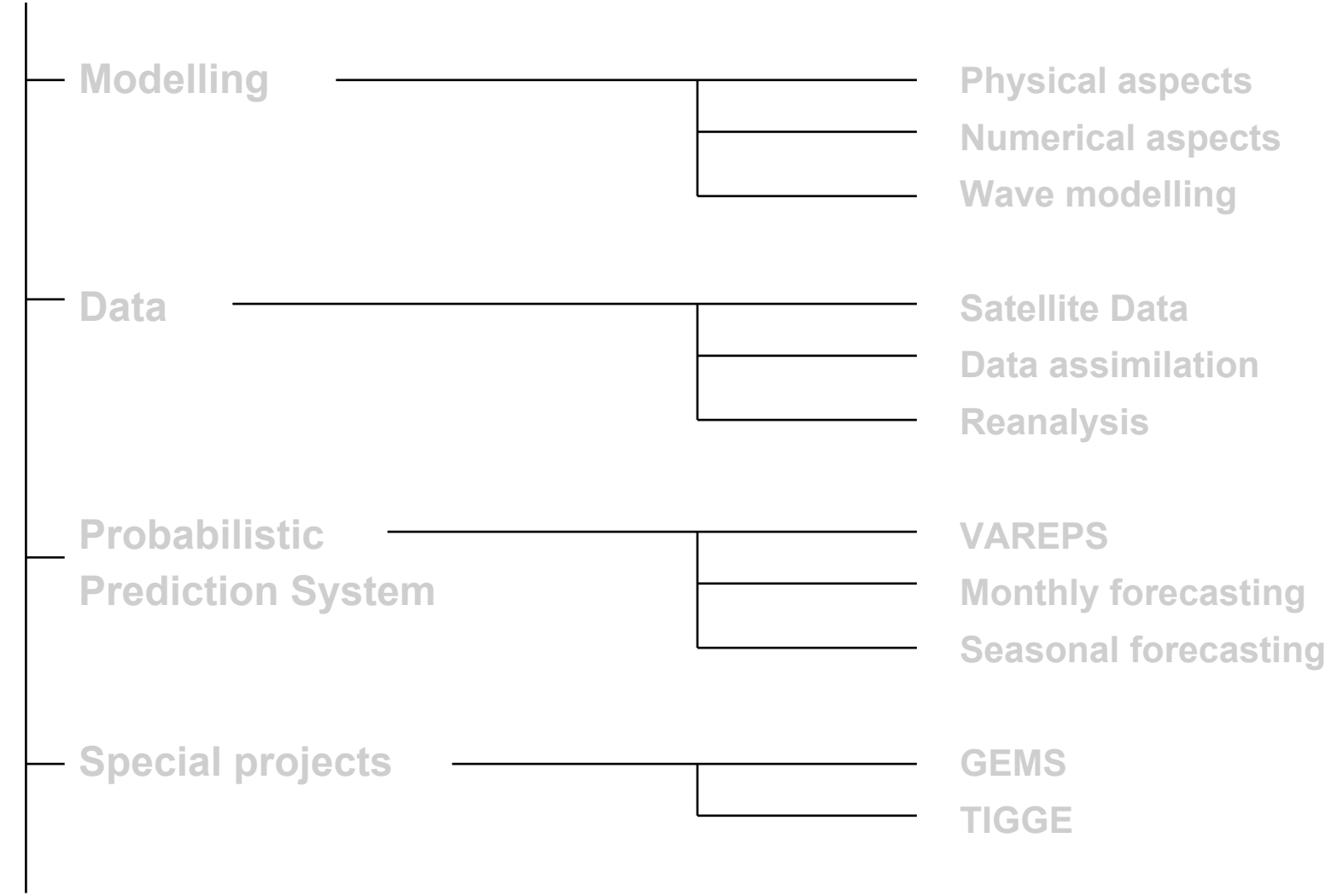
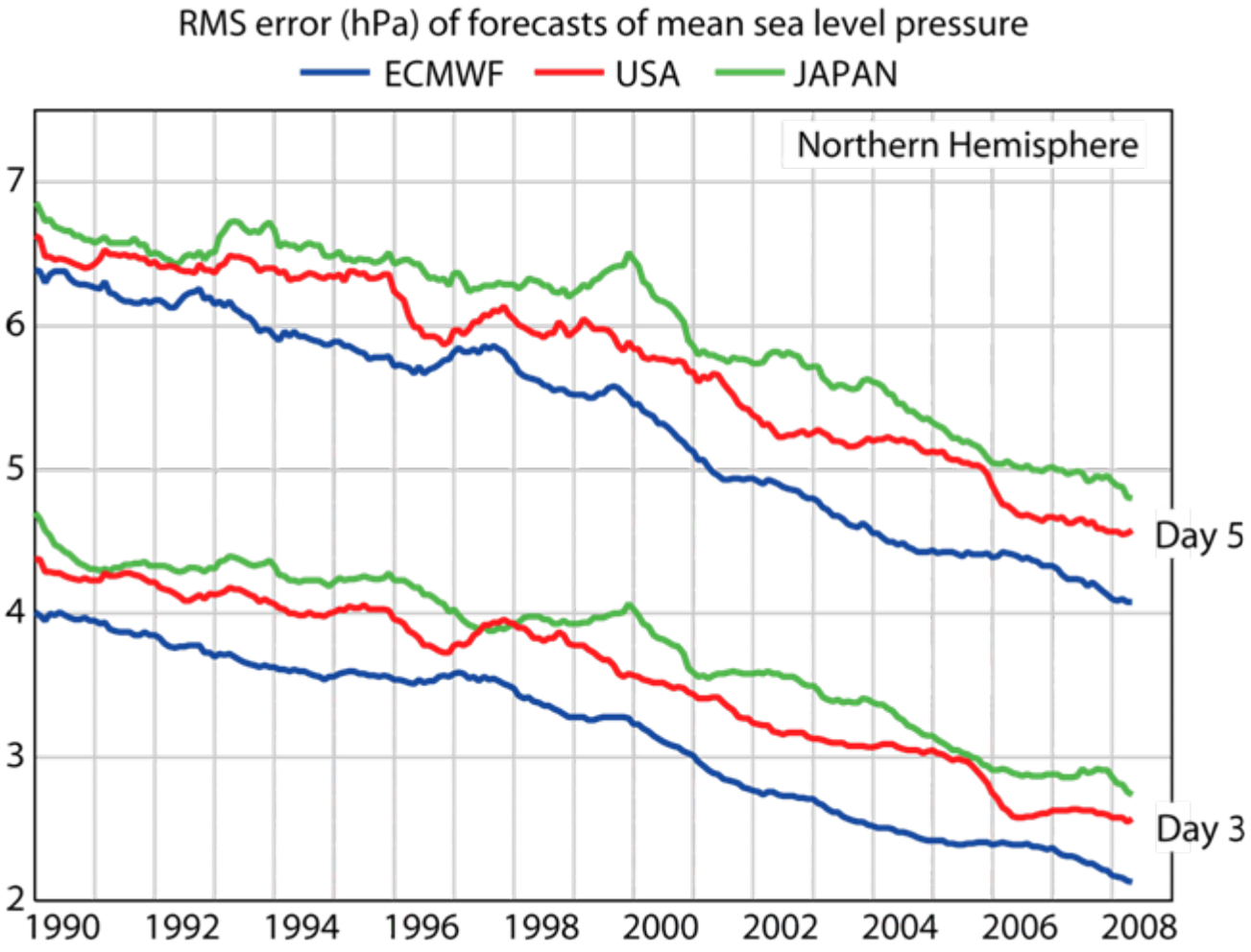


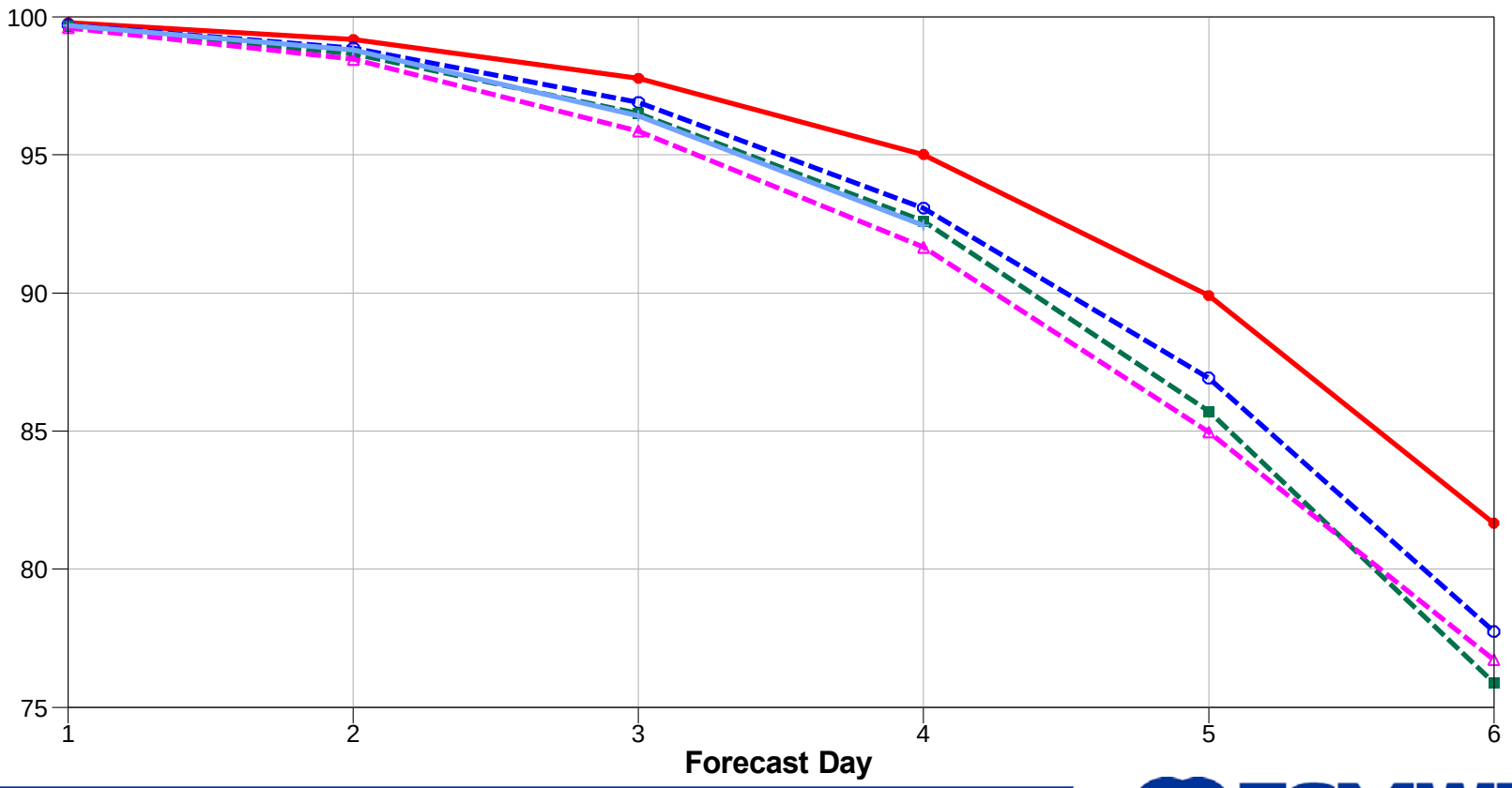
Outlook

ECMWF scores compared to other global centres



Other centres Z500 Europe

Mean curves
500hPa Geopotential
Anomaly correlation forecast
Europe Lat 35.0 to 75.0 Lon -12.5 to 42.5
Date: 20080301 00UTC to 20080531 00UTC
Mean calculation method: standard



Outlook for 2008/2009

- Direct 4D-Var assimilation of rain affected microwave radiances.
- Flow-dependent background errors from data assimilation ensemble (both for EPS and DA).
- New soil-moisture assimilation scheme (2009).
- Improvements to physics (ECOCLIMAP, stratocumulus, …).
- Migration to new supercomputer.

Outlook 2009-2010

- Implementation of the next resolution upgrade (T1279, ~16 km) shortly after the computer upgrade in 2009.
- Vertical resolution increase planned for 2010.
- Weak constraint 4D-Var accounting for model error (with the ultimate goal to extend further the assimilation time window)
- Start of 75-year reanalysis project in 2009, subject to funding.
- Completion of GEMS in 2009, to be followed by MACC (monitoring of atmospheric composition and climate) near-real time and delayed-mode global analyses.

Merci de votre attention