Development of Metrics for Coupled Prediction Systems

Hal Ritchie

Environment and Climate Change Canada

On behalf of the GODAE Ocean View Coupled Prediction Task Team (CP-TT)

Outline

- GOV Coupled Prediction Task Team (CP-TT)
- Main priorities for activities and projects
- Current CP-TT activities
- CP-TT input on desired objectives and attributes for metrics for coupled prediction systems
- Examples of related results from CP-TT members
- Summary and discussion

Coupled Prediction Task Team (**CP-TT**)

GODAE OceanView

The mission goal of the CP-TT is to draw together the international scientific and technical expertise in ocean, sea-ice and wave prediction and to seek collaboration with equivalent expert groups in atmospheric-land surface-hydrology prediction to accelerate the scientific and technical development of fully coupled systems for short- to medium-range prediction.

Co-Chairs: Chris Harris (Met Office) and Hal Ritchie (Environment and Climate Change Canada)

Focus areas for activities and projects

- Coupled prediction in an Earth Systems Modeling context but with a focus on the role of and impact on oceans (e.g., ocean-ice-wave interactions)
- Coupled data assimilation in coordination with Data Assimilation Task Team

CP-TT (continued)

Main priorities for activities and projects

- Facilitate exchange of national and international programs of scientific progress
- Collation of quantified impact of earth system coupling for ocean-wave-sea-ice-atmosphere and interfacial flux phenomena
- Foster targeted research on particular topics of interest to GOV members (e.g., SST/diurnal cycle, sea ice impacts on boundary layer fluxes, wave coupling)

CP-TT Membership

- Santha Akella, GSFC/NASA, USA
- Magdalena Balmaseda, ECMWF, UK
- Gary Brassington, BoM, Australia
- Eric Chassignet, Florida State University, USA
- Jim Cummings, NRL, USA
- Yann Drillet, Mercator-Océan, France
- Chris Harris, Met Office, UK, Co-chair
- Patrick Hogan, NRL, USA
- Patrick Laloyaux, ECMWF, UK
- Tiejun Ling, NMEFC, China
- Avichal Mehra, NOAA, USA
- Hal Ritchie, Environment and Climate Change Canada, Co-Chair
- Paul Sandery, BoM, Australia
- Gregory Smith, Environment and Climate Change Canada
- Yuhei Takaya, JMA, Japan
- Ricardo Todling, NASA/GSFC, USA
- Akiyoshi Wada, MRI-JMA, Japan

Patron champions: Hendrik Tolman (NOAA, USA), Hui Wang (NMEFC, China)

Current CP-TT Activities

- Clarify and refine the CP-TT workplan and plan some items in more detail
- Agree suitable test cases / periods for comparison of coupled / uncoupled GOV systems
- Prepare an inventory of GOV coupled systems and related plans (coupling methods including sequencing of component models, relative resolutions of components, interpolations between components, details of where flux calculations are performed, initialization, treatment of rivers, etc.)
- Build on links started with participating in WGNE-30, planning for Joint GOV-WGNE Workshop on Coupled Modelling and Data Assimilation in 2017
- Interact with the Coupled Global Modelling (CGM) Committee in the US
- Work on specific research areas (including SST/diurnal cycle)

Test cases / periods for evaluation

GODAE OceanView

- Coupled DA for polar regions, where coupling between components is very strong. It can help to assimilate ice thickness and ice concentration better, and to produce a snow analysis
- Coupled forecasting for tropical cyclones
- Coupled forecasting in strong frontal regions
- Many of these are illustrated in slides submitted by some CP-TT members related to the following activities

Recent Developments

- CP-TT helped shape and support the international workshop on “High-resolution ocean modelling for coupled seamless prediction” (HRCP) held at the Met Office in Exeter UK, 13-15 April 2016. Members Magdalena Balmaseda, Eric Chasignet, Chris Harris, Pat Hogan, Tiejun Ling and Hal Ritchie participated.
- Hal Ritchie presented an “Update on GODAE OceanView and its Coupled Prediction Task Team” by remote participation in WGNE 31 in Pretoria, South Africa on 26 April 2016.
- CP-TT co-convened a special session on “Coupled Modelling and the Year of Polar Prediction at the Canadian Meteorological and Oceanographic Society Congress in Fredericton NB Canada 29 May – 2 June 2016. Member Avichal Mehra gave a lead-off invited presentation on coupled modelling at NCEP and Hal Ritchie gave an overview of coupled modelling in CONCEPTS.
- Members Magdalena Balmaseda, Chris Harris and Hal Ritchie are participating in the organizing committee for the WMO Working Group on Data Assimilation and Observing Systems (DAOS) international workshop on coupled data assimilation announced for 18-21 October 2016 at Météo-France in Toulouse FR.

Recent Developments (continued)

- We are considering organizing a focused CP-TT meeting. One suggestion is a comparison of coupled system configurations and performance. In preparation we would accelerate our inventory of GOV coupled systems and related plans, agree and initiate suitable test cases and periods for comparison of coupled and uncoupled systems. Motivated by the HRCP workshop discussions, this should include developing appropriate metrics in collaboration with the GOV IV-TT. Eric Chasignet indicated willingness to host such a meeting in Fall 2017, although there may be an earlier opportunity.
- We would appreciate continuing consultation and interaction with WGNE, the DA-TT and the IV-TT on these options.

CP-TT input: Priority Research Areas

- JMA plans to develop a relatively high-resolution model (55km for atmosphere, 0.25 degrees for ocean) for the next seasonal prediction system, which would provide some scientific basis for subseasonal coupled prediction. Ocean coupling is important for subseasonal to seasonal (S2S) prediction and CP-TT should link with the WWRP/WCRP S2S project.
- At NOAA plans are afoot for CFS v3 which will include a fully coupled 7 component system with Atmosphere-Ocean-SeaIce- Waves- Land-Aerosols - Ionosphere components for both data assimilation and forecasts. For Medium Range, test skill of MJO amplitudes and phases. For long term, ENSO variability is a stated goal for coupled systems. Seasonal variability of oceanic water mass transformations. Skill in first month US surface 2m Temperature and precipitation which would include getting skill in coupled data assimilation and forecasts.

Priority Research Areas (cont'd)

- At ECMWF increase of atmospheric resolution to TCo639 (15 km) to day 10 and TCo319 to day 15/45. Increase of ocean resolution to ORCA025. Introduction of dynamic sea-ice model. This is a coupled ensemble prediction system, with 50 members, up to 15 days twice a day, and up to 42 days twice weekly. The physical coupling includes atmosphere-ocean-land-ice-waves. The waves interact with the atmosphere and ocean, and work is ongoing for the ice-wave interaction. Research areas include coupled data assimilation for reanalyses (producing a XX-century coupled reanalysis with conventional data and a high-resolution coupled reanalysis for the satellite era), and for initialization of coupled forecasts (improve the use of surface observations in different media, thus improving surface analysis and reducing initialization shock).

Priority Research Areas (cont'd)

- NRL has examined bias estimates from ocean analyses and forecasts using dynamically based calibrations to characterize resulting ocean forecast errors. HYCOM is 2-way coupled with CICE. The plan is to extend forecasts to 14 days, including ice, by Fall 2018.
- FSU is examining the impact of horizontal resolution (1/12 to 1/50 degree) on Gulf Stream Separation and penetration. Other factors being held constant, it all seems to come together with the emergence of sub-mesoscale eddies at 1/50 degree.
- NMEFC is examining the importance of resolving the diurnal cycle of SST and sea skin temperature in coupled models. They developed a new mixed layer model that improves both the amplitude and phase, and find that it has important impacts on regional weather and climate in a coupled model.

Priority Research Areas (cont'd)

- ECCC continues the research, development and implementation of coupled prediction systems within the context of the Canadian Operational Network of Coupled Environmental PredicTion Systems (CONCEPTS). Upgrades have been recently made to the GEM-NEMO-CICE coupled Gulf of St. Lawrence (GSL) system that is now running at higher resolution over the Laurentian Great Lakes where it is improving forecasts both for the atmosphere and the water bodies. The ¼ degree Global Ice-Ocean Prediction System (GIOPS) is now in full operational status, and a 1/12 degree regional version (RIOPS) is running experimentally. A coupled GEM-NEMO-CICE system is running experimentally for deterministic medium-range forecasts and is in development for ensemble seasonal prediction.

CP-TT Input: Coupled System Metrics

- To first order, metrics for coupled systems should be the same as for uncoupled, e.g., for SST, Sea level, winds, T2m, …
- Need diagnostics to evaluate impact of coupling: observation impact across media, co-variability, closure of budgets, initialization shock.
- Particular focus on tropics, tropical cyclones, and impact of interactive sea-ice.
- Need metrics to assess impacts of coupling on a process level: surface fluxes, surface stresses, roughness, …
- Need metrics to measure pumping of heat and moisture to the upper troposphere.

Environment Canada Environnement Canada

Canada

Impact of Ocean and Sea Ice Coupling on Global Medium-range Weather Forecasts:

The Coupled GDPSv6.0.0 Experimental Forecast System

H Ritchie[1], GC Smith[1], F Roy[1], J-M Belanger[1], P Pellerin[1]

M Roch[1], Y Chartier[2], D Surcel Colan[2], B Winter[2]

D Deacu[2], R Muncaster[1],

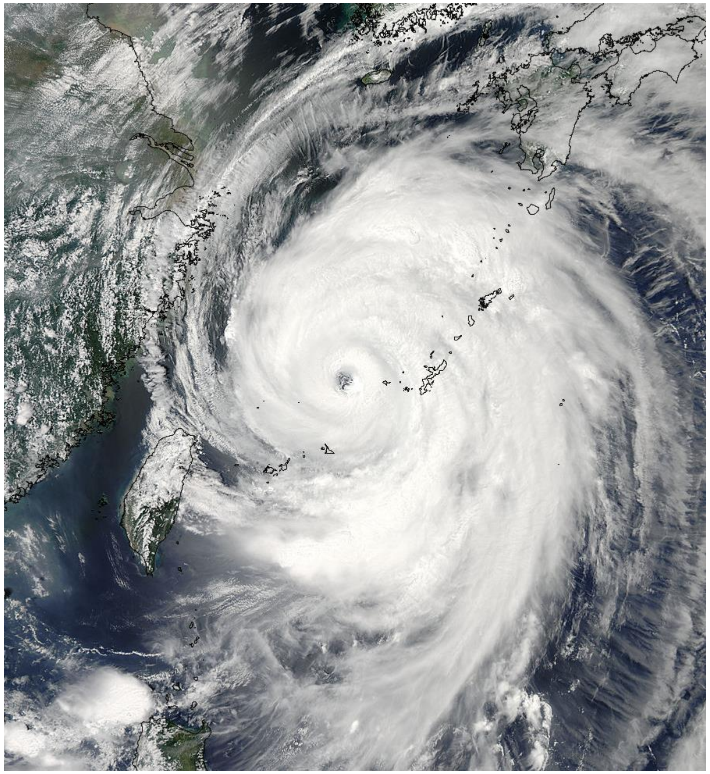
JS Fontecilla[2], A Zadra[1], B Archambault, M Reszka[2], Y Liu[2], W Yu[2], E Lapalme[2] , R McTaggart-Cowan[1], M Desgagne[1], P Vaillancourt[1], M Charron[1], …

and the CONCEPTS Team

…

[1] Meteorological Research Division,

[2] Meteorological Service of Canada



IV-TT, Sep 20-22, 2016

Environment Canada

Fisheries and Oceans Canada

Mercator Ocean Ocean Forecasters

CONCEPTS

National Defence

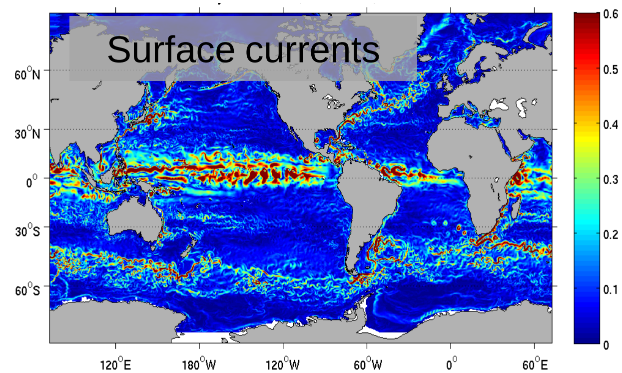
Ice-ocean modelling with NEMO + CICE

Applications and domains

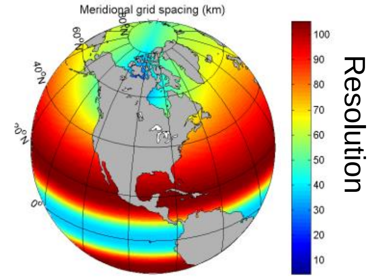
Operational
Experimental
In development

- Global 1/4° resolution (GIOPS)
  - Medium-monthly forecasting
  - Fully-coupled for NWP
- Global 1° resolution (CanSIPS-GN)
  - Seasonal forecasting
- N. Atlantic and Arctic 1/12° (RIOPS)
  - Short-to-medium range forecasting
  - Coupled HRDPS-Polar for YOPP
- Great Lakes 2km (RMPS-GL)
- Gulf of St. Lawrence 5km (RMPS-GSL)
  - Short-term forecasting

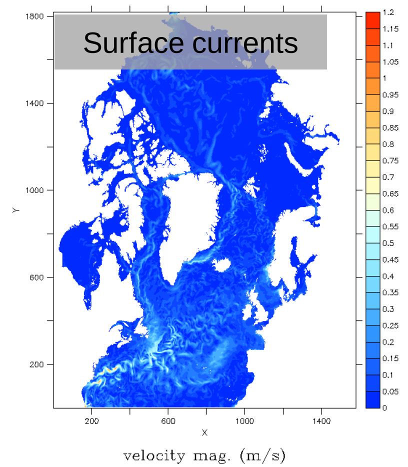
1/4° Global

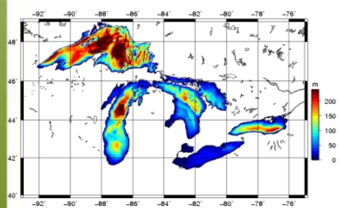


1° Global



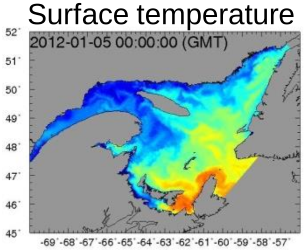
1/12° N. Atlantic and Arctic





Bathymetry

Surface temperature

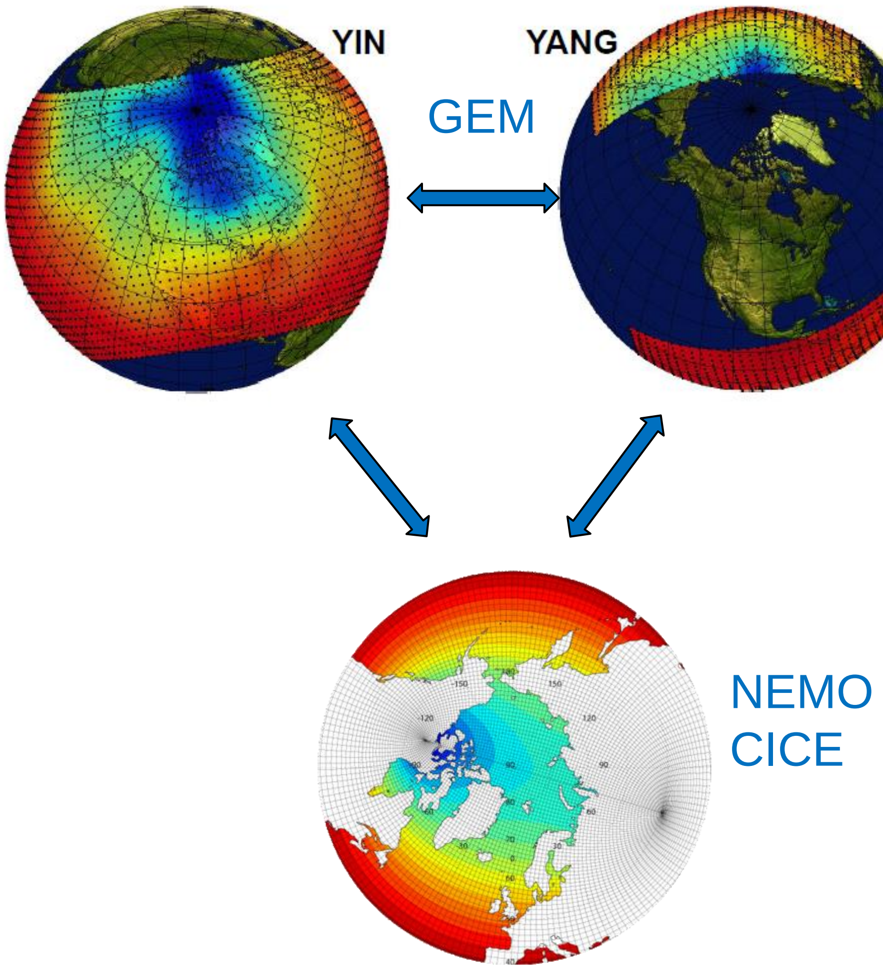


CONCEPTS
CANADIAN OPERATIONAL NETWORK OF COUPLED ENVIRONMENTAL PREDICTION SYSTEMS

Environment Canada | Fisheries and Oceans Canada | National Defence Défense nationale | Mercator Ocean Ocean Forecasters | Canada

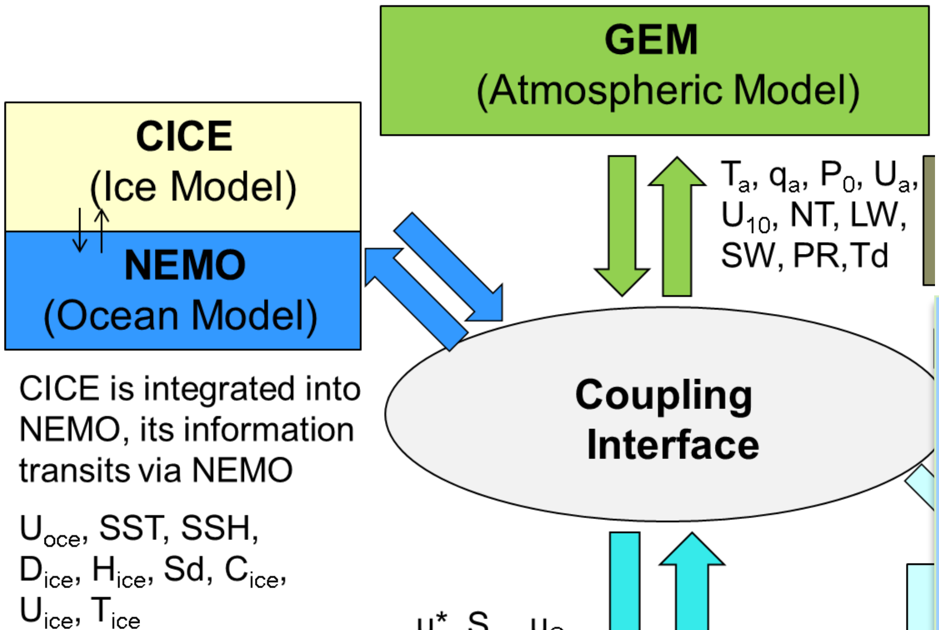
Global Coupled Medium-range Deterministic Forecasts

- Coupled NWP system running in operations at CCMEP since 8 July 2016.
  - GDPS coupled to GIOPS
  - Global, fully-coupled A-I-O, 25km(A)-1/4deg(IO),
  - 10 day forecast (2/day)
- Available on RPNWMS:
  - E.g. www.meteocentre.com/plus
- MSC datamart (soon)
  - Atm: GRIB2, Ocean/Ice: Netcdf4

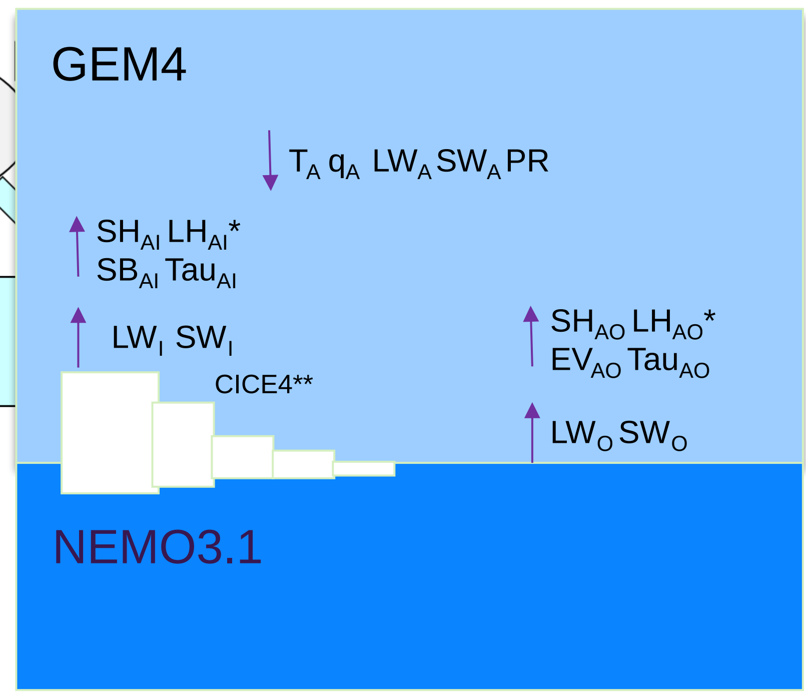


Coupling Method

Same method used by Gulf of St. Lawrence, Great Lakes, GDPS and Seasonal Systems



Flux Coupling via GOSSIP socket server



- Coupling every timestep
- Calculate fluxes on fine-scale grid and aggregate

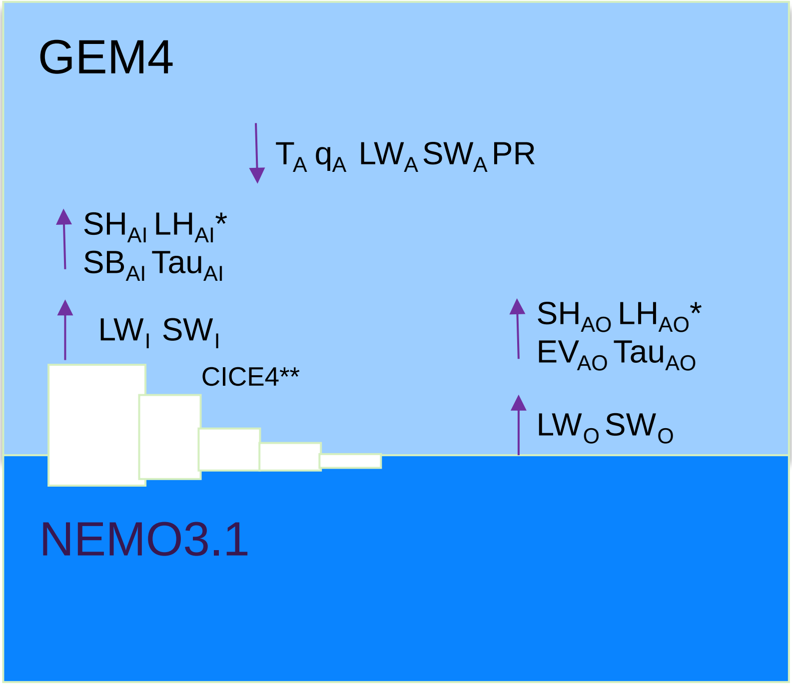
Jean-Marc Belanger, Francois Roy, Natacha Bernier

Coupling Method

Same method used by Gulf of St. Lawrence, Great Lakes, GDPS and Seasonal Systems

- To produce forecasts that exchange fluxes between GEM and NEMO/CICE at every timestep:
  - Calculate fluxes in NEMO/CICE using GEM flux library
  - Regridding done in respective models using pre-calculated weights
  - Surface fluxes in GEM are only modified where coupling mask is activated (i.e. over the ocean)
  - Exchange fluxes at every timestep using GOSSIP socket server over TCP/IP
- Allows for efficient exchanges and independent model evolution

Flux Coupling via GOSSIP socket server

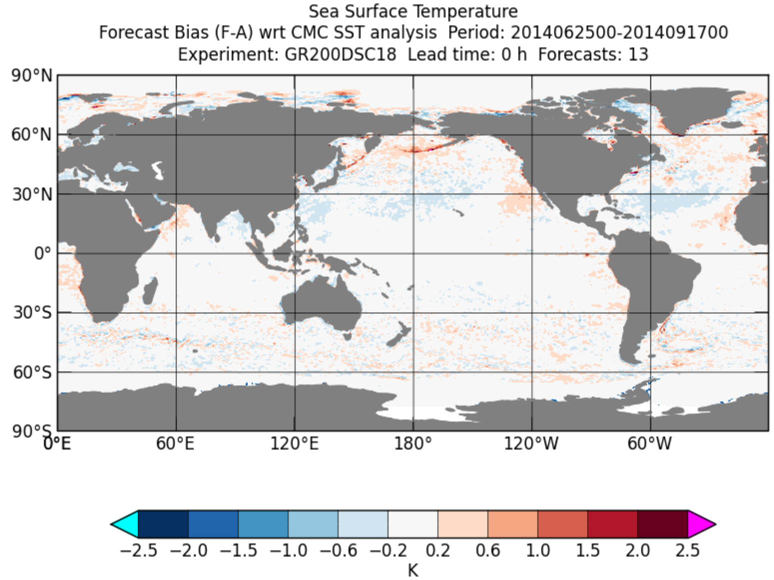


Comparison with CMC SST Analysis

Mean differences for 2014-06-25 to 2014-09-17

- Special attention paid to SST assimilation
  - Differences mostly < 0.2°C
  - Some areas show differences of up to 0.6°C (N. Pac)
  - Largest errors in summer
- Provide closest SST to that used during atmospheric assimilation (EnVAR)
  - Minimize initialization shock
- Improved under-ice SST assimilation substantially reduces differences with CMCSST

GIOPS – CMC SST analysis



How to measure initialization shock in coupled models?

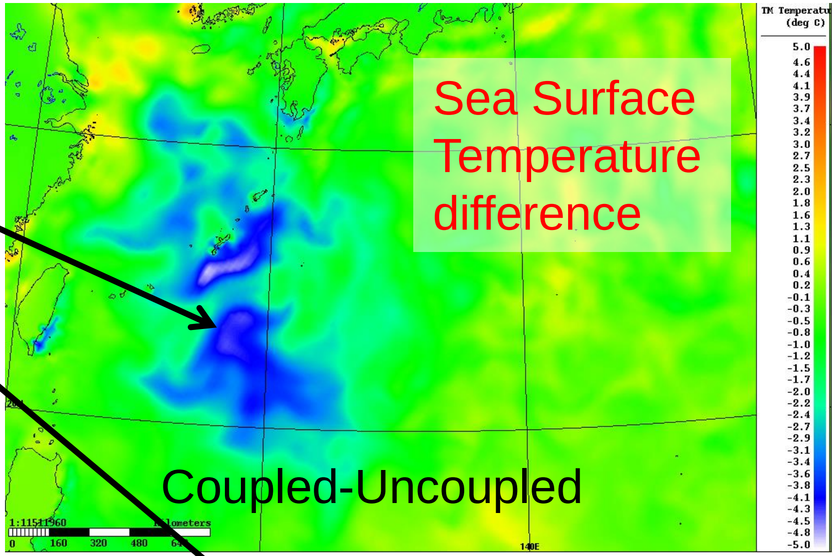
Where to differences in fluxes originate?

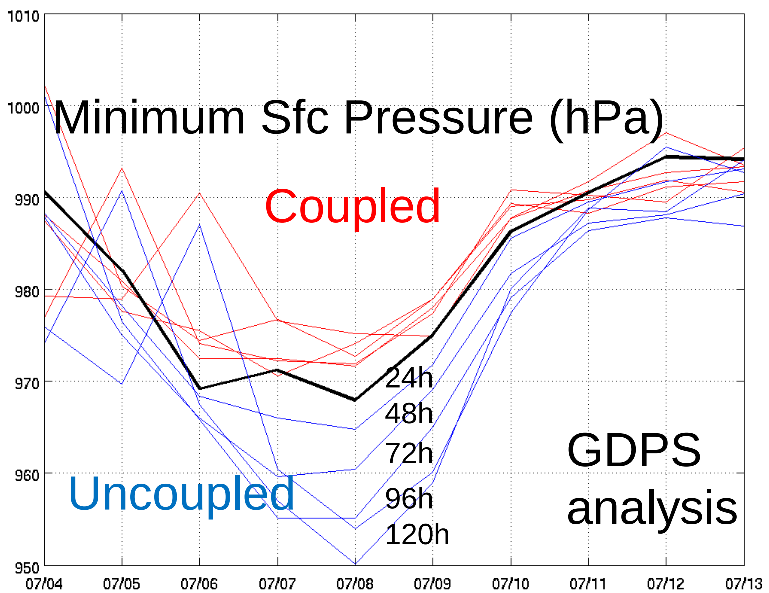
- Differences in SST and sea ice initial condition
  - GL, I7, I8, SD
- Evolution of ocean/ice fields over 10 days
  - Seasonal cycle, diurnal cycle, small scale features (leads)
- NEMO uses saturation vapour pressure for salt water
  - Results in a 2% reduction (i.e. 0.98*qsat)
- Fluxes across sea ice take into account ice thickness categories
- CICE ice surface temperature calculated taking ice enthalpy into account (induces time lag)

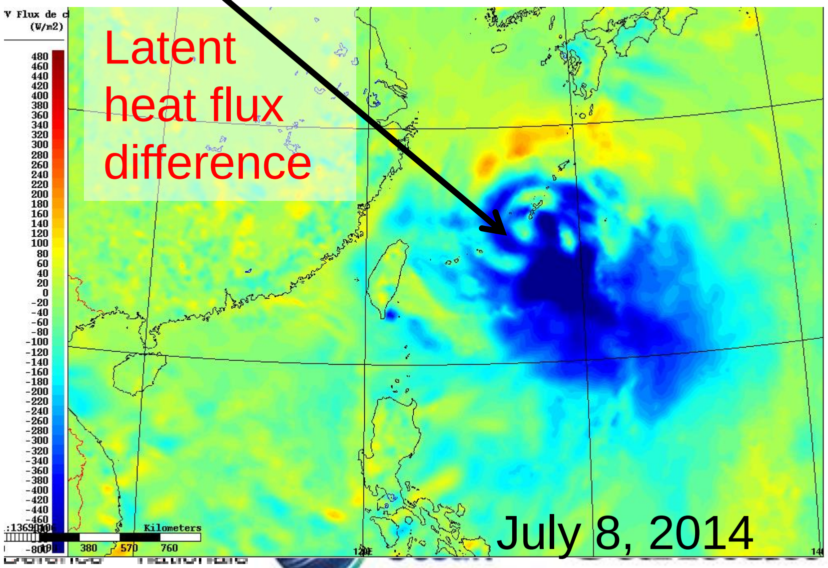
Impact of Coupling on Forecasts for TC Neoguri

96h forecasts, valid 00Z, July 10, 2014

- Coupling results in ~4°C cooling of sea surface temperature
- with associated >500 W/m2 reduction in latent heat flux
- Leads to reduced intensification at all lead times (24-120h)

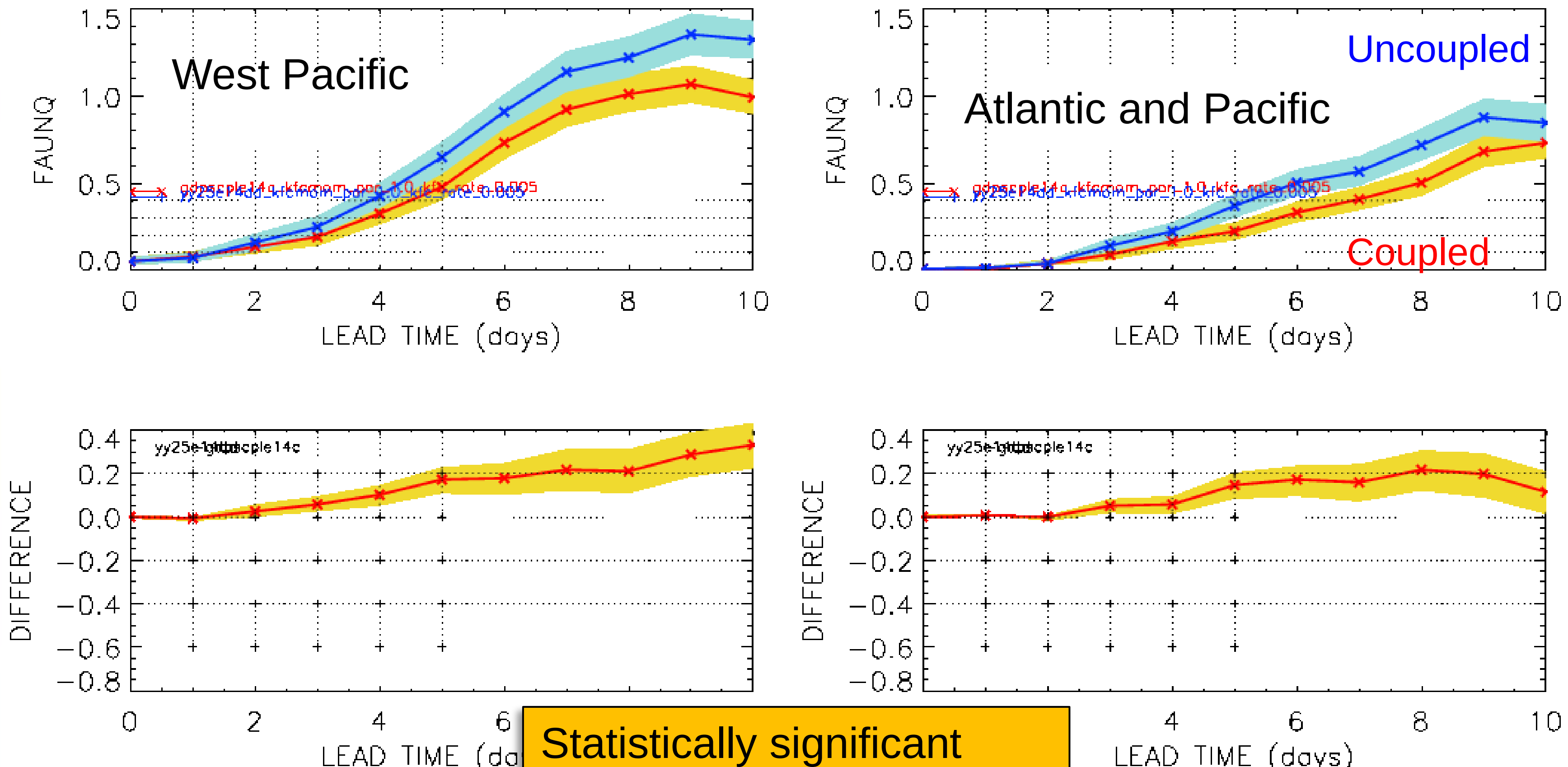






Unequivocal False Alarm Rate

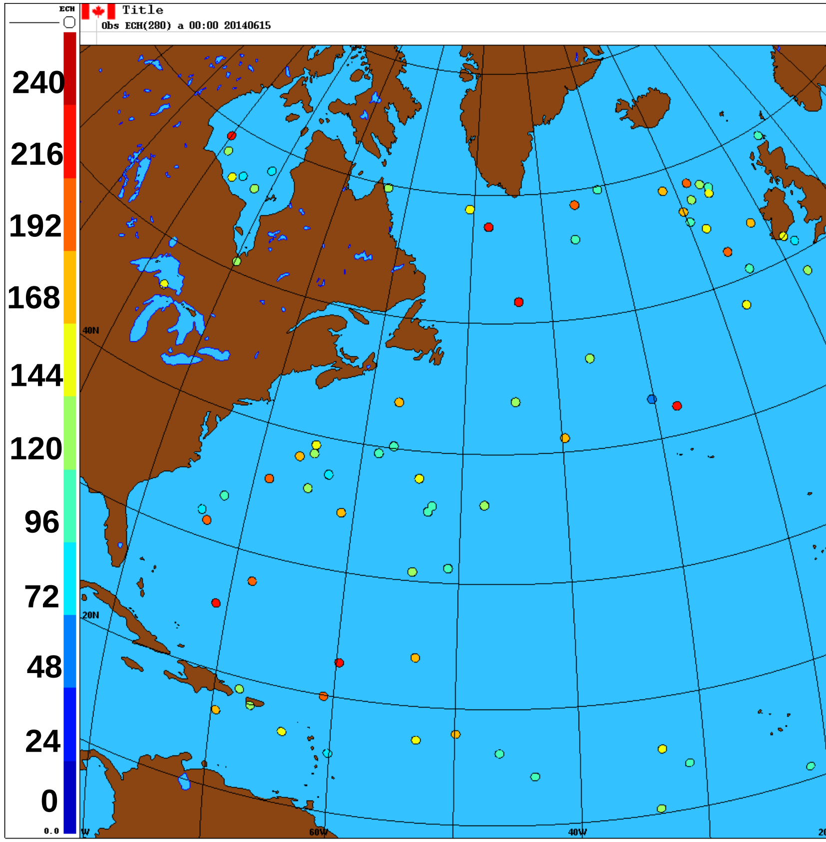
Storm tracking thresholds set as in Zadra et al. (2014)



Statistically significant reduction for days 3-10

Unequivocal False Alarms during Summer 2014
(Only points of 1st occurrence are displayed)

Lead time of 1st occurrence (hours)

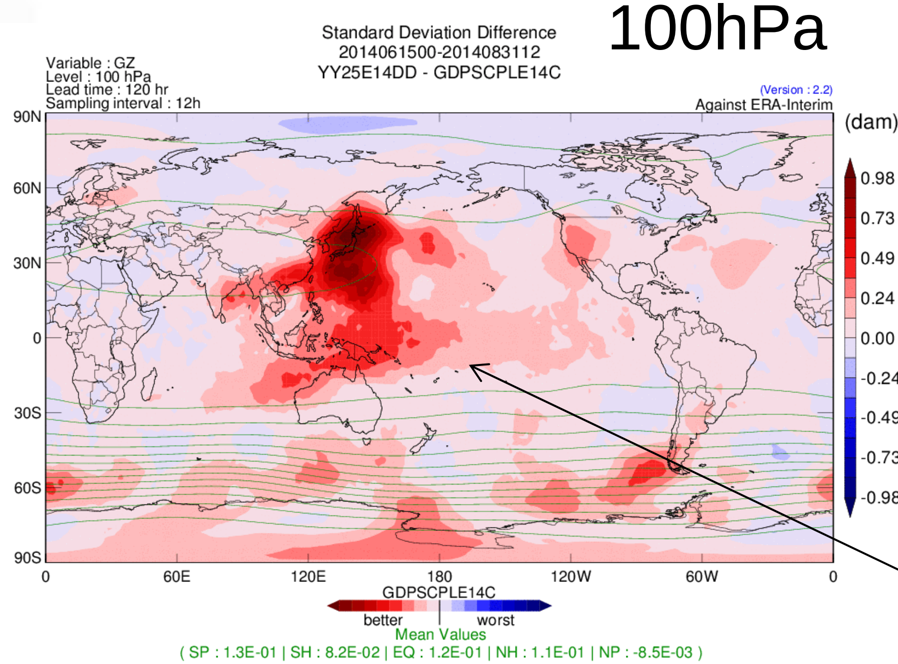


Uncoupled (72 pts)

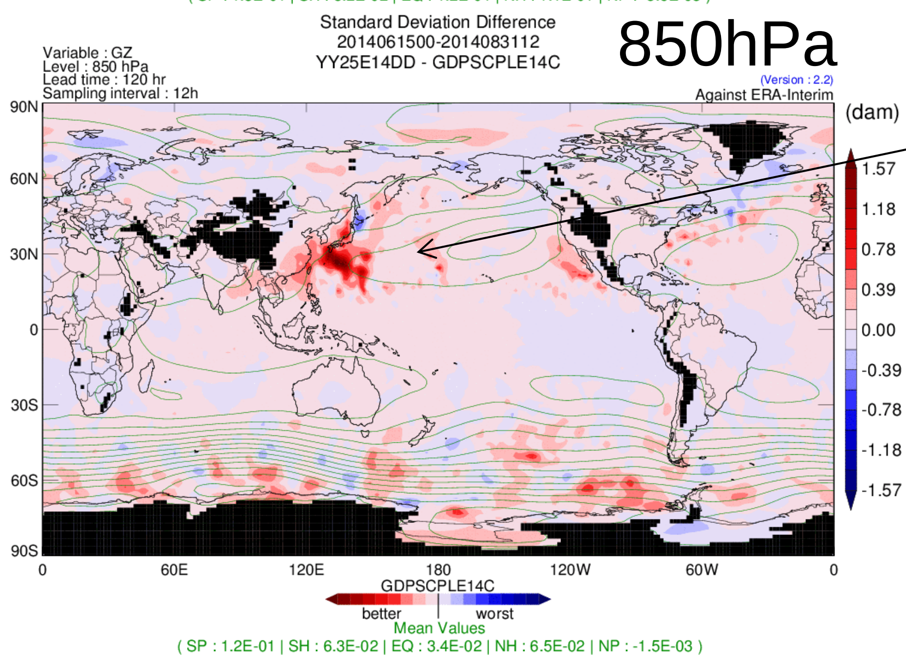
GZ@120H

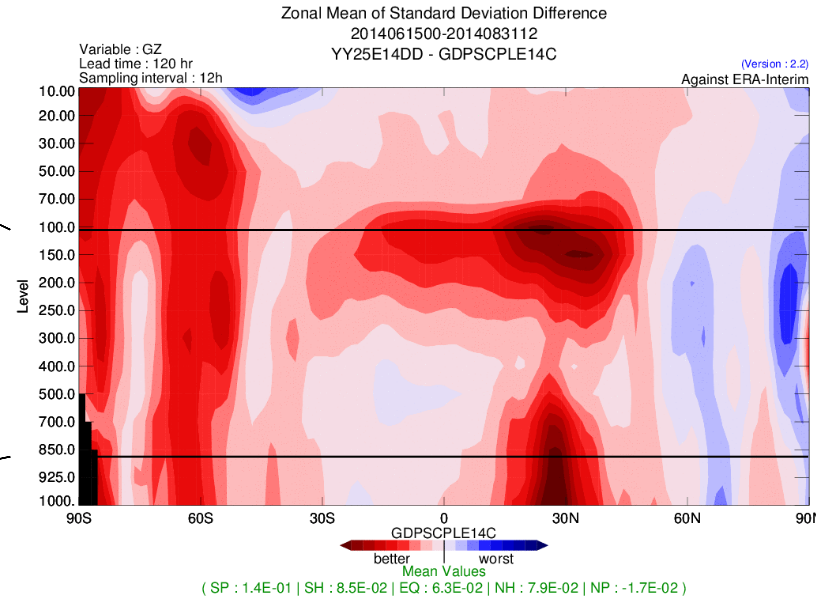
Summer 2014

100hPa



850hPa



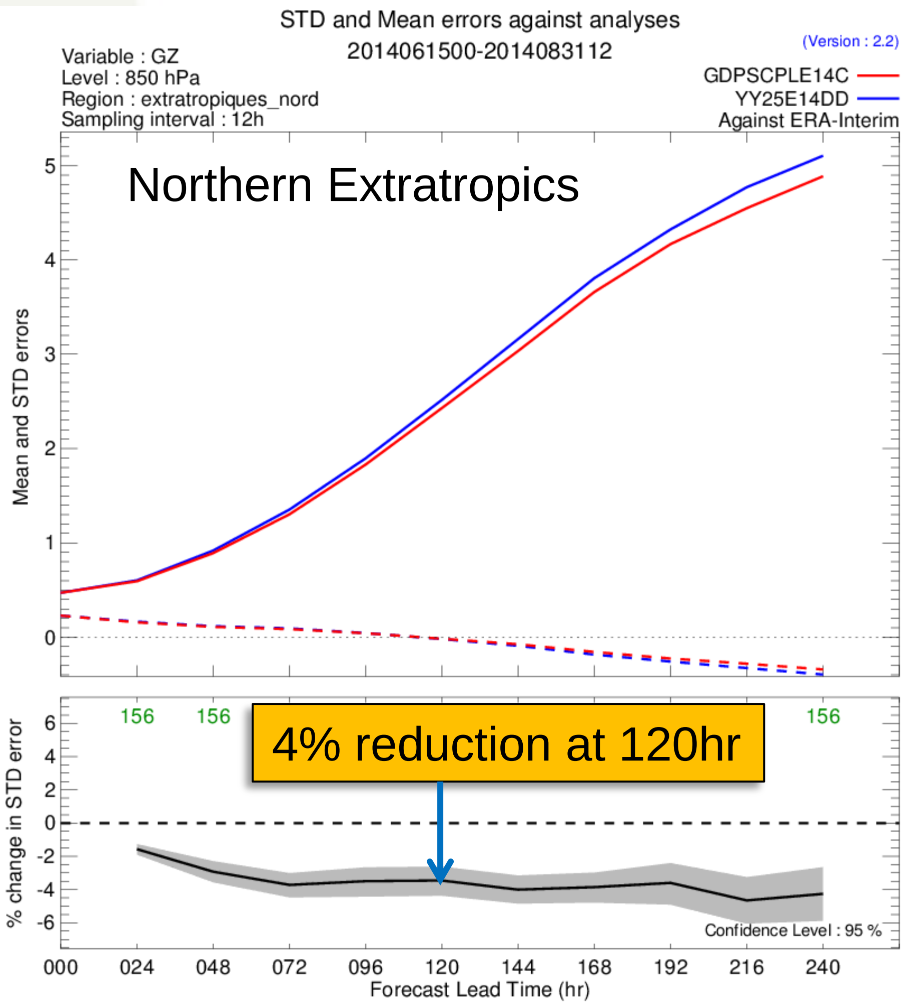


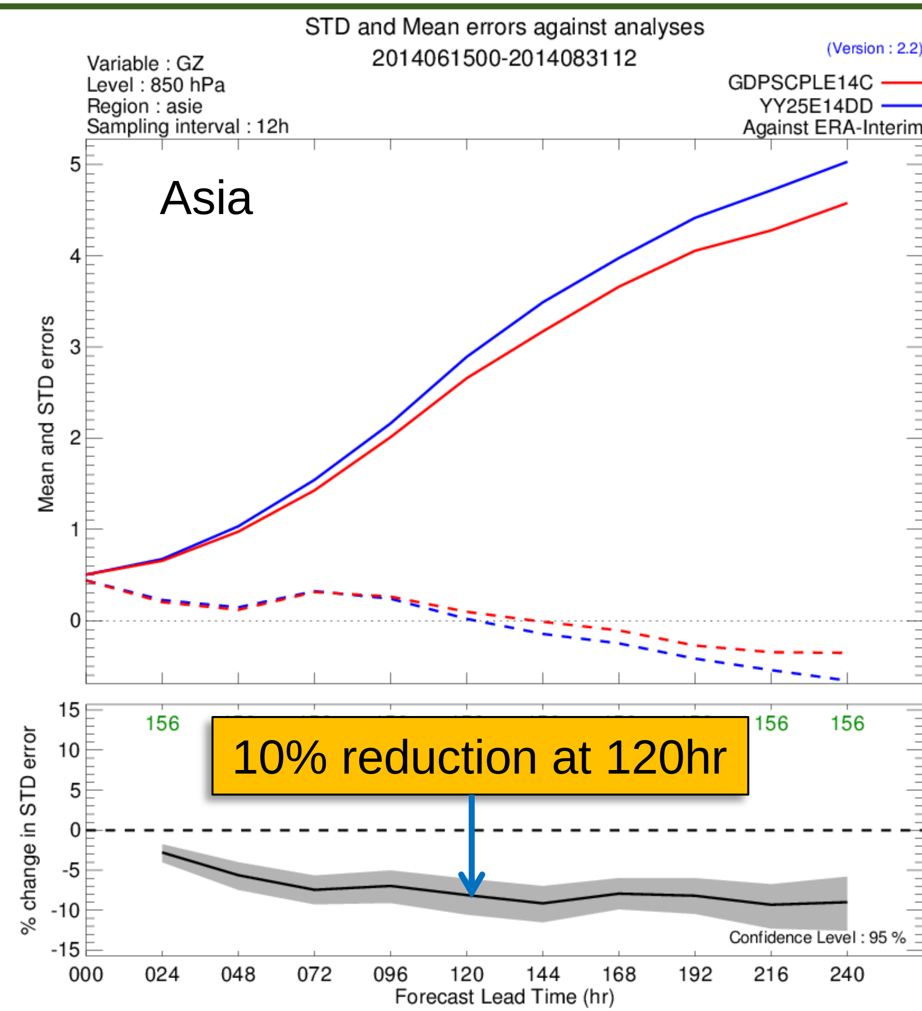
We need verification scores that can measure pumping of heat and moisture to upper troposphere

nal Défense
nce nationale
Mercator Ocean
Ocean Forecasters
Canada

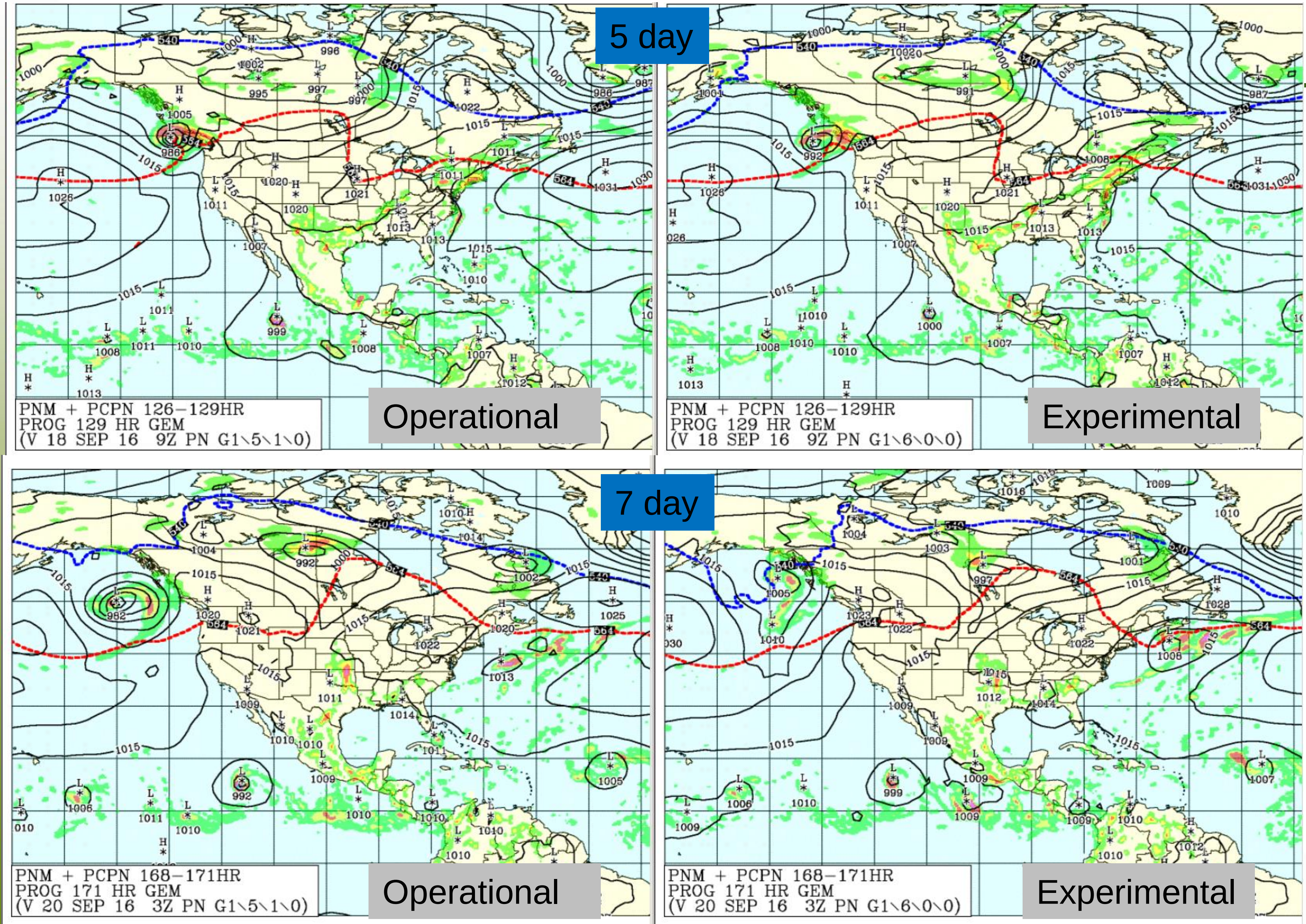
Summer 2014

Geopotential Height at 850hPa





Forecast issued Sep 13, 2016 , 00Z



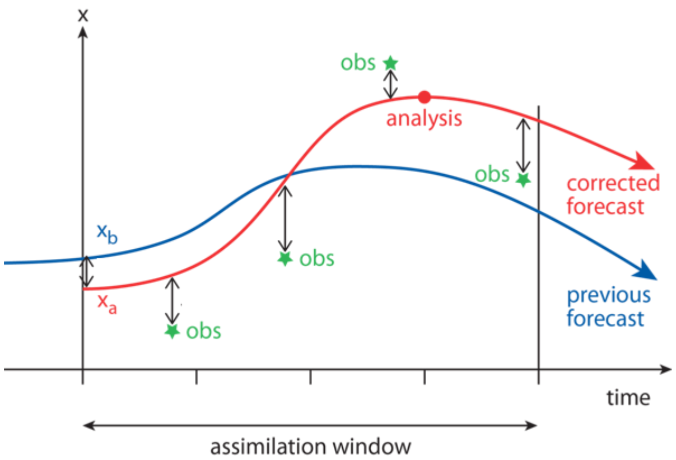
Earth-system modelling and assimilation at ECMWF

Patrick Laloyaux
Earth System Assimilation Section
patrick.laloyaux@ecmwf.int

Acknowledgement: Eric de Boisseson, Magdalena Balmaseda, Kristian Mogensen, Gianpaolo Balsamo, Hao Zuo, Massimo Bonavita, Yannick Trémolet, Elias Holm, Sarah Keeley, Franco Molteni, Frederic Vitart, Simon Lang, Antje Weisheimer, Paul Poli, Hans Hersbach, Per Dahlgren, Dinand Schepers, Yuki Kosaka, Shoji Hirahara, Adrian Simmons, Dick Dee, Roberto Buizza

EUROPEAN CENTRE FOR MEDIUM RANGE WEATHER FORECASTS

Data assimilation at ECMWF



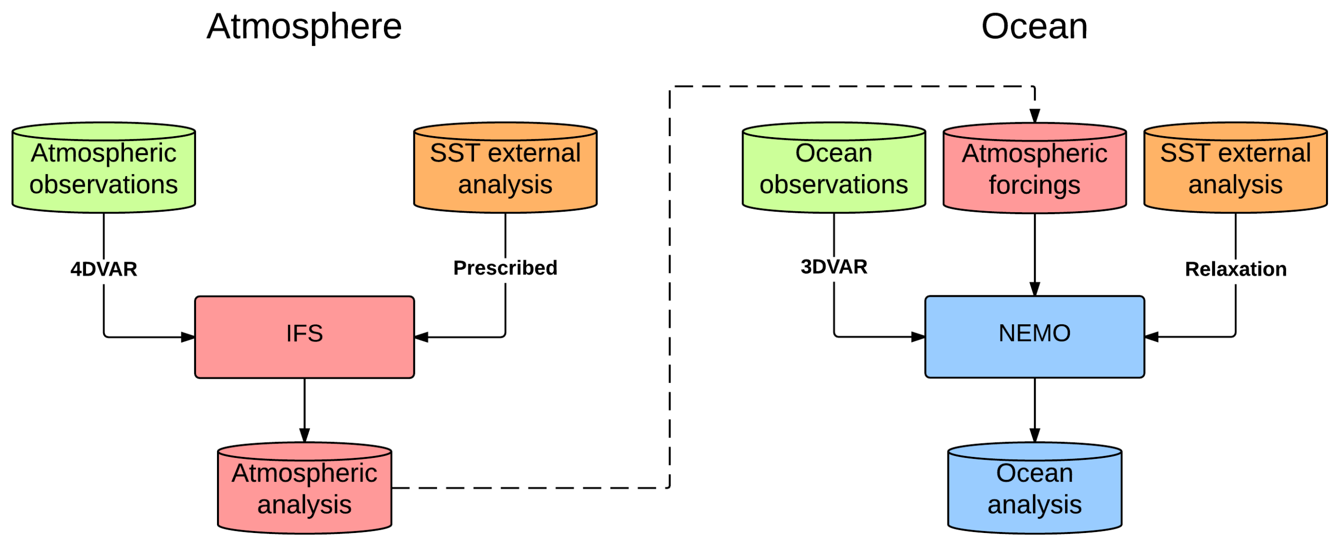
For each component of the Earth system:

- a short-range forecast from the previous cycle
- available observations in the assimilation window
- assimilation scheme to produce an analysis trajectory
- a corrected short-range forecast for the next cycle

Data assimilation systems have been developed separately for each component:

- **atmosphere: 4D-Var**
- **ocean: 3D-Var**
- sea-ice: 3D-Var
- wave: OI
- land: OI and SEKF
- atmospheric composition: 4D-Var

Link between atmospheric and ocean assimilation



Ocean analysis:

- NEMO model
- 3D-Var (10-day assimilation window)
- atmospheric forcings (computed from the atmospheric analysis with a bulk formula)

Ocean-S4
ORCA1 Z42 grid
5 members (perturbed observations and forcings)

Sea Surface Temperature is based on an external analysis:

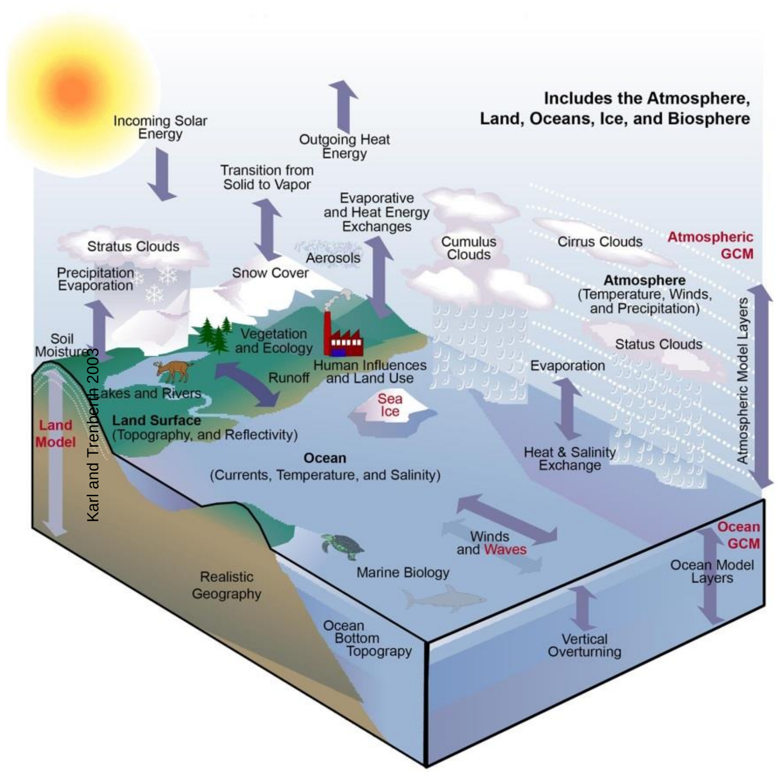
- prescribed in IFS
- relaxed in NEMO

Earth-system modelling for weather forecast

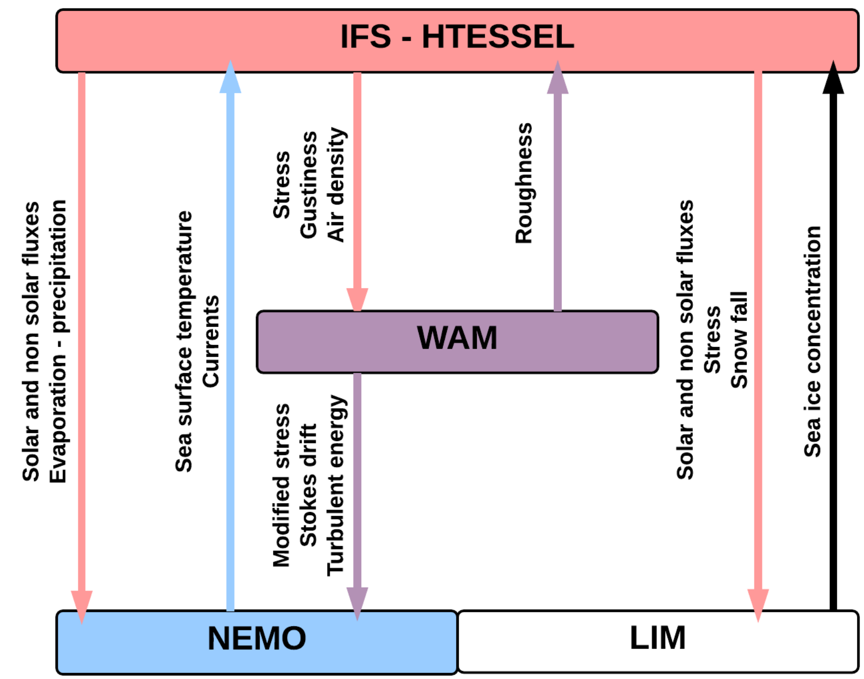
Atmospheric and ocean analyses (initial conditions) are computed separately, but atmosphere and ocean are coupled in the forecasts

An earth system approach with advanced modelling techniques

Earth system physical processes



Coupled earth model for weather forecasts

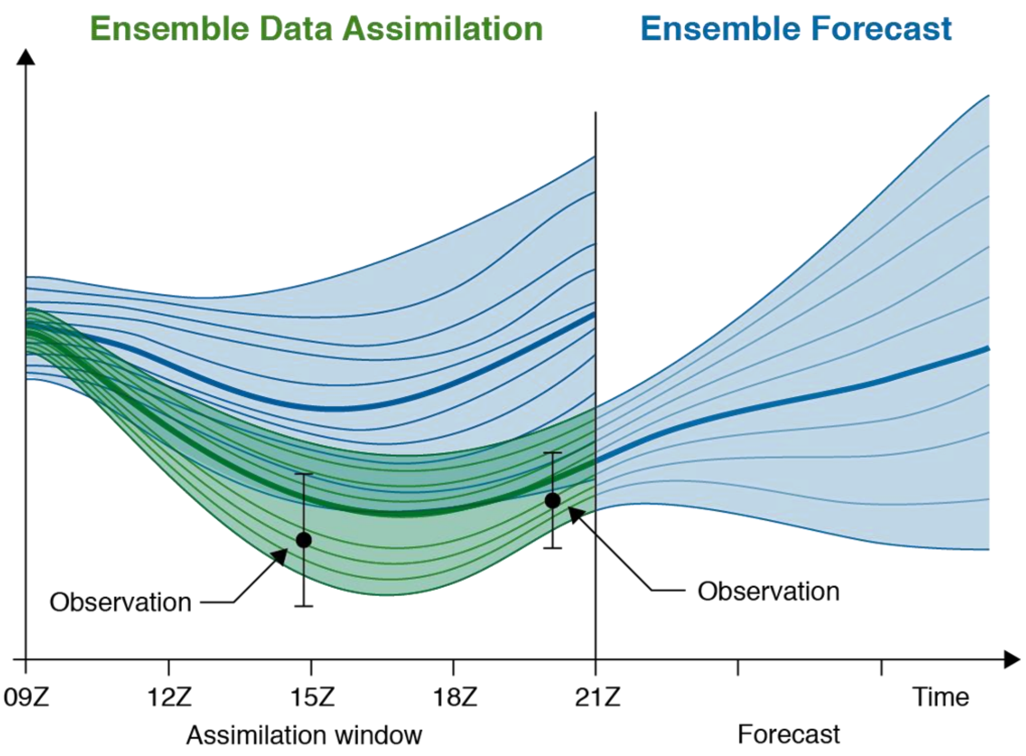


→ active research (G. Balsamo & J. Bidlot)

Coupled earth model for the ensemble prediction system (ENS)

The ENS system is the ECMWF ensemble prediction system for the medium-range and monthly timescales

- Perturbations from EDA members (with singular vectors) are used to initialise the atmospheric component of ENS
- Ocean-S4 is used to initialise the ocean component of ENS



ENS system
50 members
Days 1-15: TCo639 L91
Days 16-46: TCo319 L91

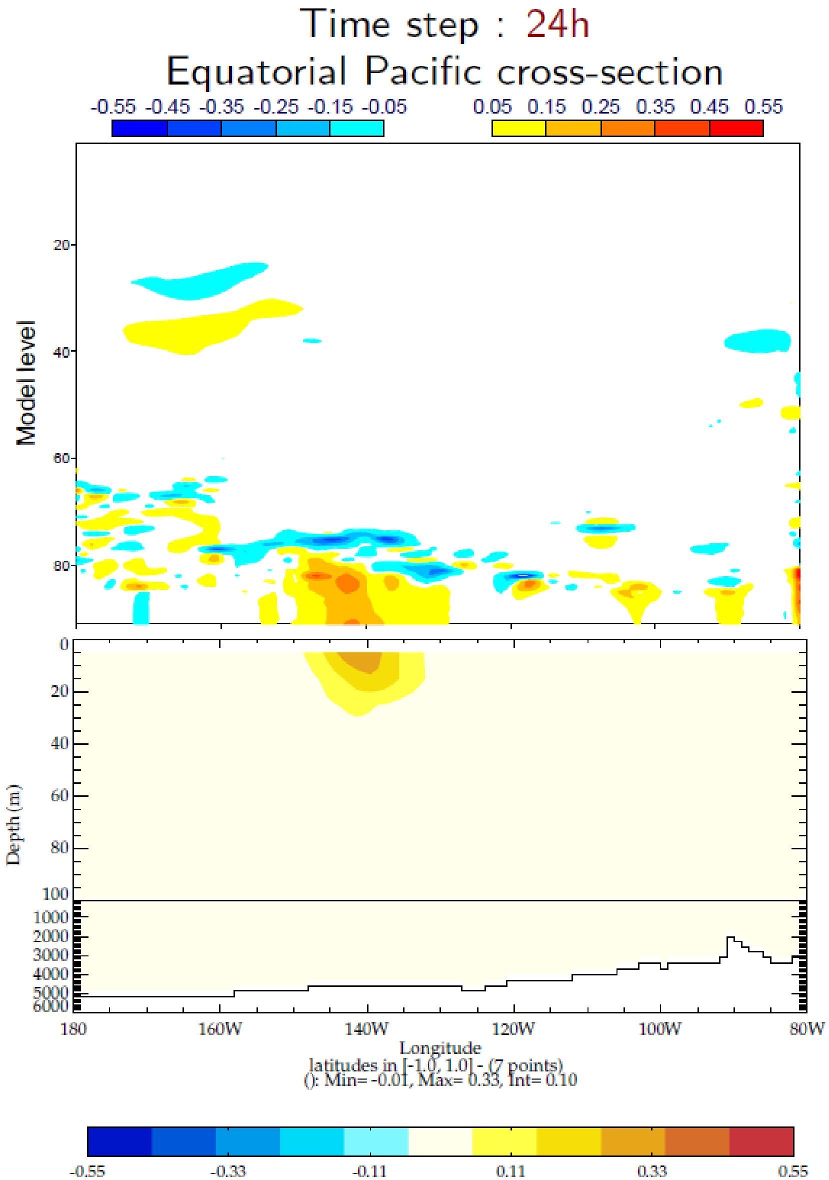
Coupled atmosphere-ocean assimilation system (CERA)

Atmosphere-ocean interactions need to be taken into account, not only during the forecast but also for the definition of the initial conditions of the forecasts

A new coupled assimilation system (CERA) for the coupled model:

- the coupled earth model is used for assimilation
- atmospheric and ocean observations assimilated simultaneously
- a common 24-hour assimilation window for atmosphere and ocean
- ocean observations can impact atmospheric estimate and conversely

Information exchange in the CERA system

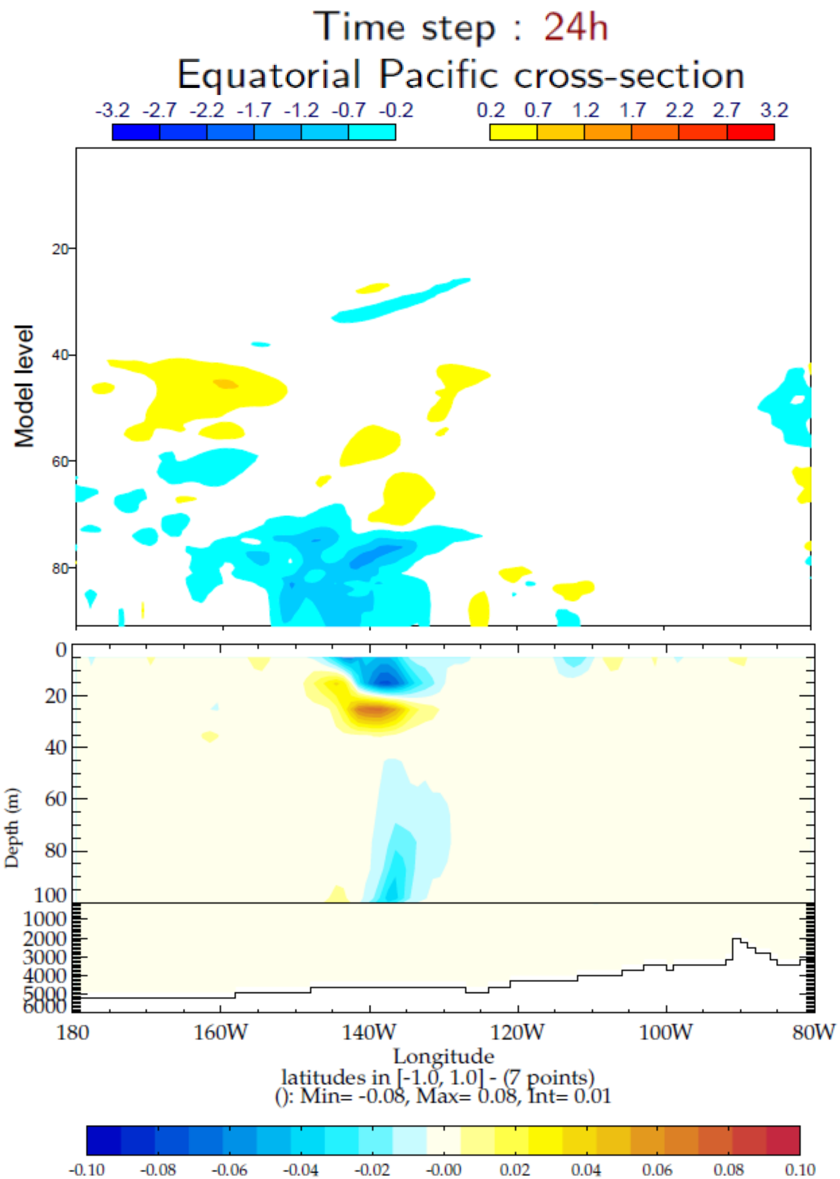


Atmosphere-ocean temperature cross-section

Ocean increment (assimilation of one temperature observation at 5-meter depth) spreads in the atmosphere during the model integration (outer loop)

Coupled analysis should be better balanced and consistent with respect to the coupled model

Information exchange in the CERA system



Atmosphere-ocean cross-section (wind and temperature)

Atmospheric wind increment (one station with hourly measurements of a 10m/s westward wind) spreads in the ocean as a temperature increment during the model integration (outer loop)

Ocean-atmosphere correlations are generated within the CERA incremental variational approach

A coupled data assimilation system for climate reanalysis. P. Laloyaux, M. Balmaseda, D. Dee, K. Mogensen and P. Janssen. QJRMS, 142: 65–78, 2016.

Two new extended climate reanalyses at ECMWF

ORA-20C: the first ECMWF ocean reanalysis of the 20th century

Ocean

Sea ice

Model: NEMO/LIM2 (CY41R2, Mar 2016)
Forcing: SST nudged (HADISST2) and ERA-20C
Observation: salinity and temperature profiles
Assimilation: 3D-Var (10-member ensemble)
Resolution: ORCA1 Z42
Period: 1900-2010

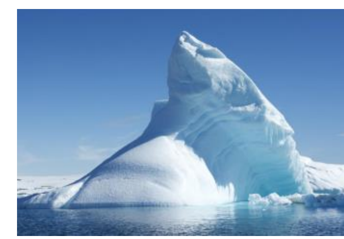
CERA-20C: the first ECMWF coupled reanalysis of the 20th century

Atmosphere

Land

Wave

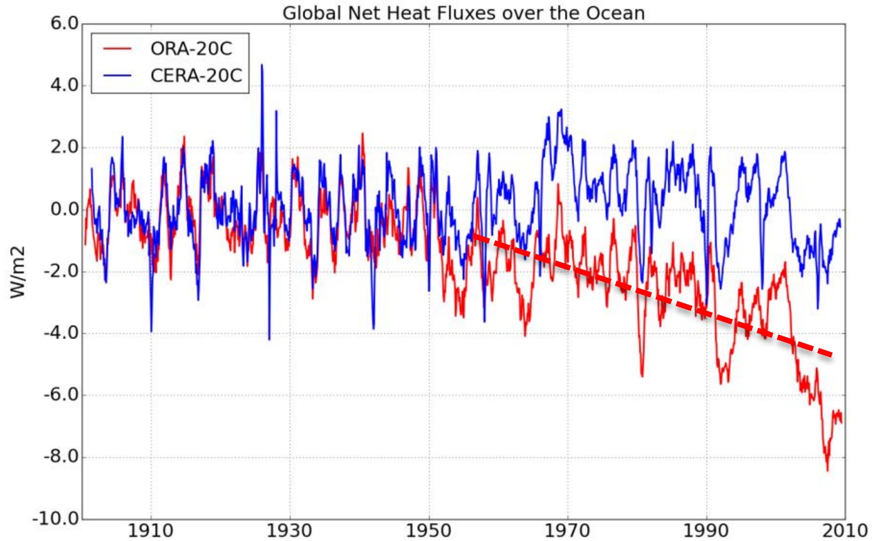
Ocean



Sea ice

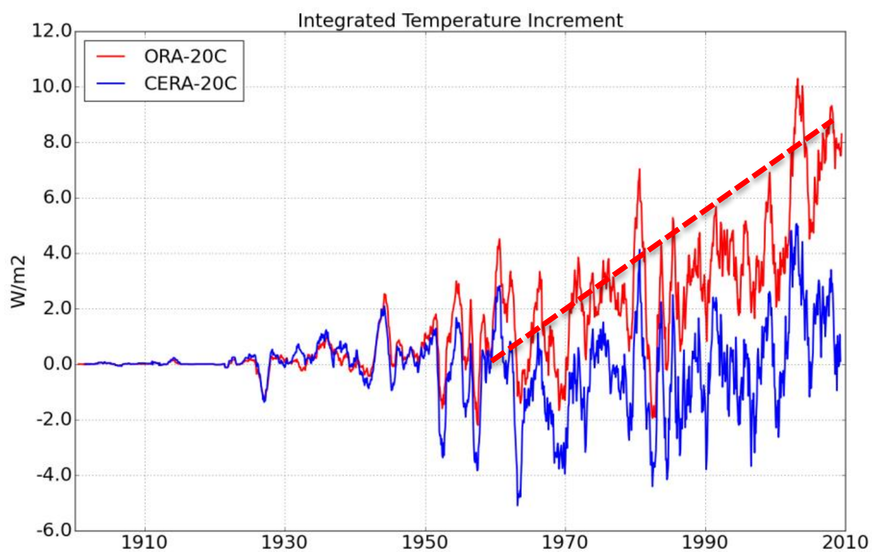
Model: IFS/NEMO/LIM2 (CY41R2, Mar 2016)
Forcing: SST nudged (HADISST2)
Observation: surface conventional, salinity and temperature profiles
Assimilation: new CERA system (10-member ensemble coupled hybrid DA)
Resolution: T159L91/ORCA1 Z42
Period: 1901-2010

Preliminary results of CERA-20C



Global net **air-sea fluxes** toward the ocean in CERA-20C and ORA-20C.

→ spurious trend in ORA-20C probably due to shift in wind forcing in ERA-20C



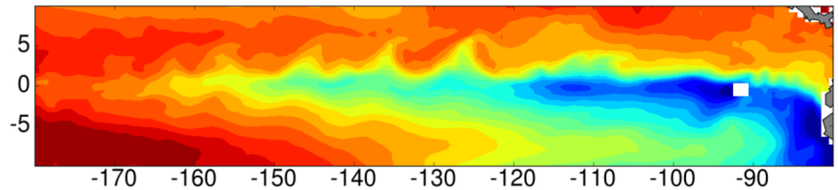
Ocean temperature increment in CERA-20C and ORA-20C.

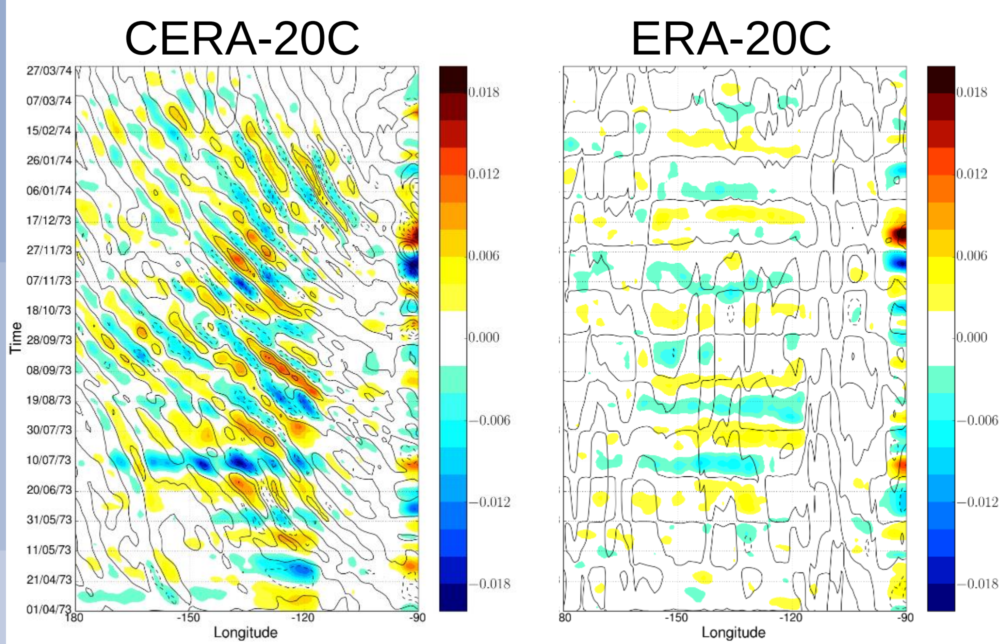
→ increment in ORA-20C is trying to compensate for the trend in the net fluxes
→ CERA-20C is a much more balanced system

Courtesy of E. de Boisseson

Preliminary results of CERA-20C

Tropical Instability Waves (TIW) are westward-propagating waves near the equator (intraseasonal coupled process)





high-pass filtered SST (colour) and wind stress (contour)

CERA-20C
→ represents TIWs thanks to the ocean dynamics
→ atmosphere is responding accordingly (surface wind stress is sensitive to the ocean TIW)

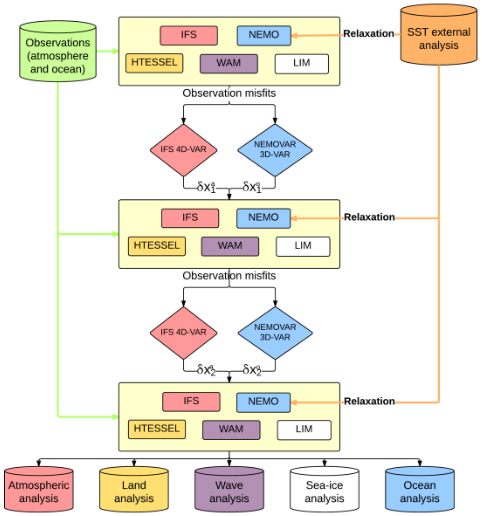
ERA20C
→ does not capture the TIW and wind stress signals (forced by monthly SST)

Courtesy of E. de Boisseson

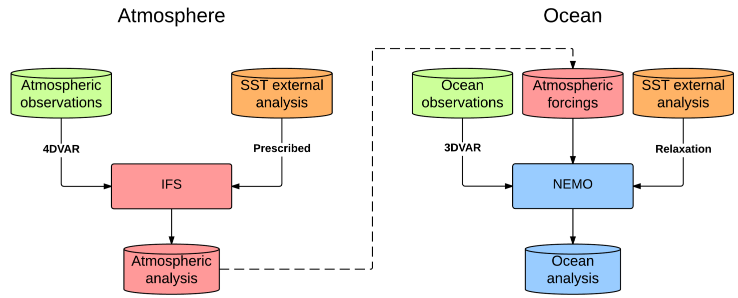
CERA system for Numerical Weather Prediction

CERA system has been compared to the uncoupled approach over recent periods

CERA



UNCPL



To get a fair comparison, an UNCPL system has been set up using:

- same model cycle
- same resolution
- 1-day assimilation window for ocean and atmosphere
- same number of outer and inner iterations
- run for Apr-May 2010, Aug-Sept 2010 and Dec-Jan 2010/2011

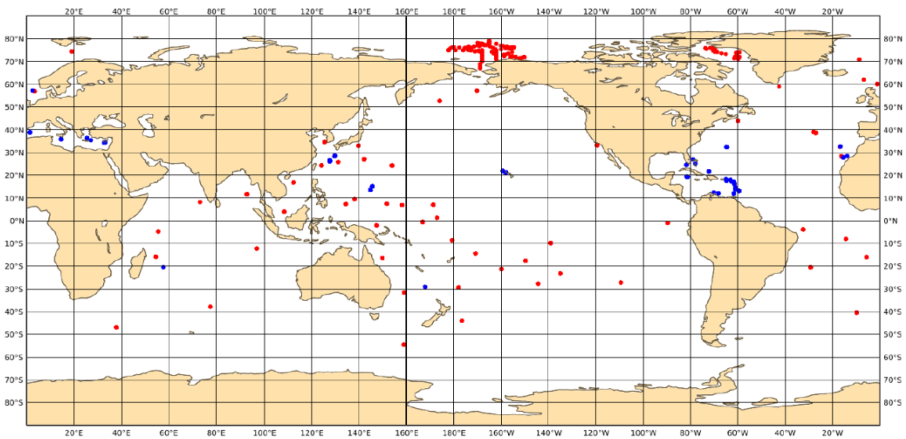
Possible improvements in the coupled analysis?

Possible improvements in the use of near-surface observations?

Possible improvements in the initialisation of coupled forecasts?

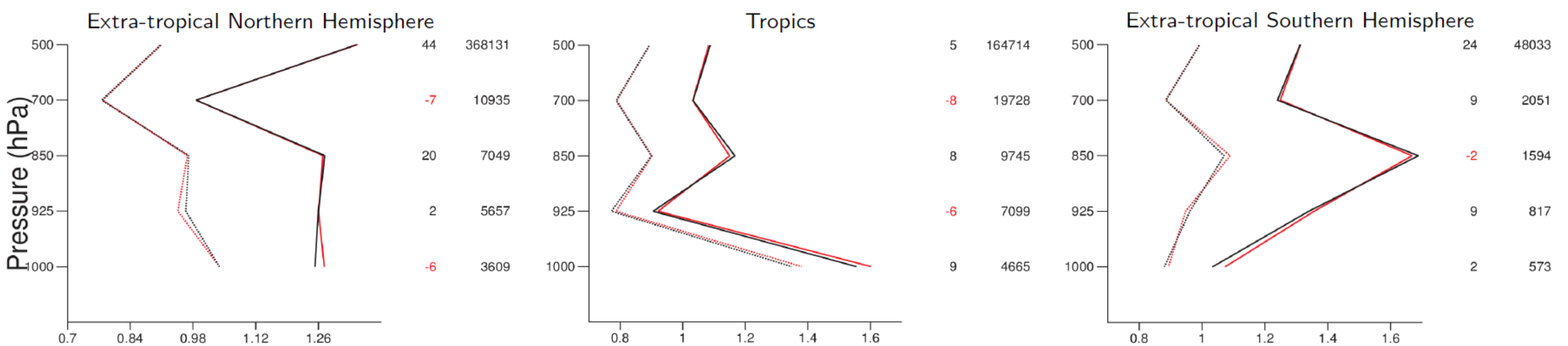
Quality of the coupled analysis - Atmospheric temperature

Conventional near-surface temperature observations over sea (lsm<0.1, p>700hPa, Sep 2010)



Radiosondes
aircrafts

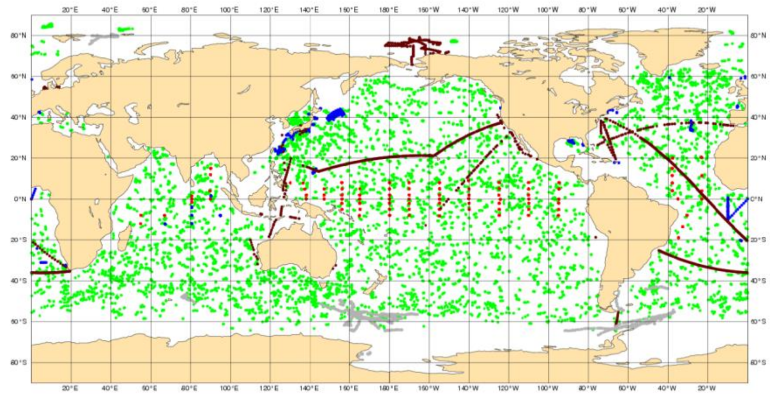
CERA compared to UNCPL – Vertical profiles for the analysis RMSE (dashed) and background RMSE (solid) for September 2010 with respect to the selected observations



The CERA background RMSE is slightly smaller near the surface, neutral elsewhere
Same conclusions for May 2010 and January 2011

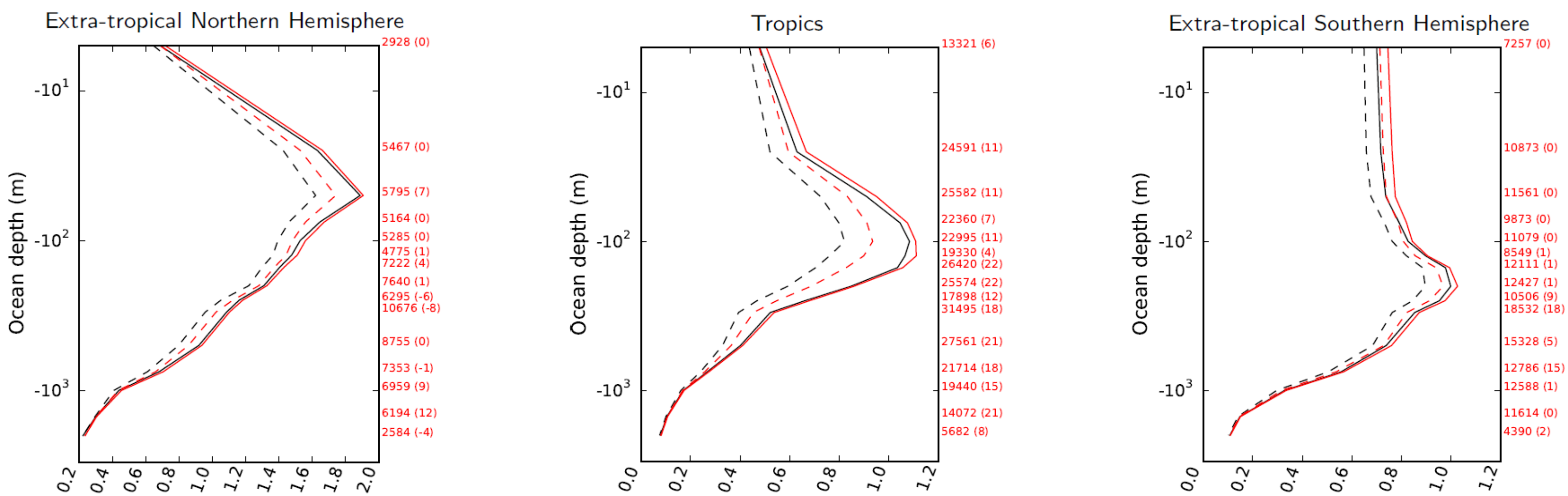
Quality of the coupled analysis - Ocean temperature

Conventional ocean temperature profiles (Sep 2010)



Argo
Moorings
CTD
XBT
Marine mammals

CERA compared to UNCPL – Vertical profiles for the analysis RMSE (dashed) and background RMSE (solid) for September 2010 with respect to the observations

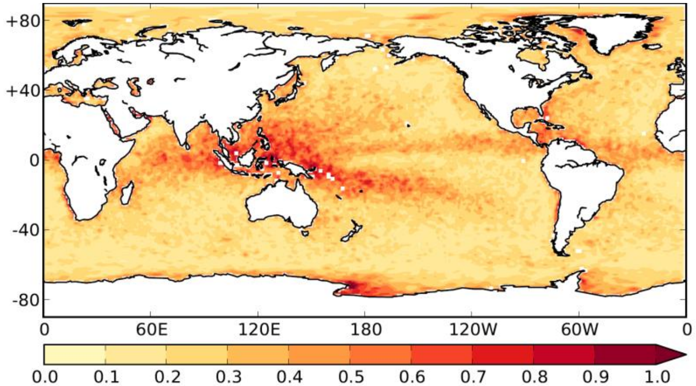


The CERA background and analysis RMSE are smaller in the mixed layer
Same conclusion for May 2010 and January 2011

Initialisation of coupled forecasts

Error in the coupled forecasts initialised by **CERA** analysis

1000hPa temperature RMSE after 12 hours versus own analysis



model drift:

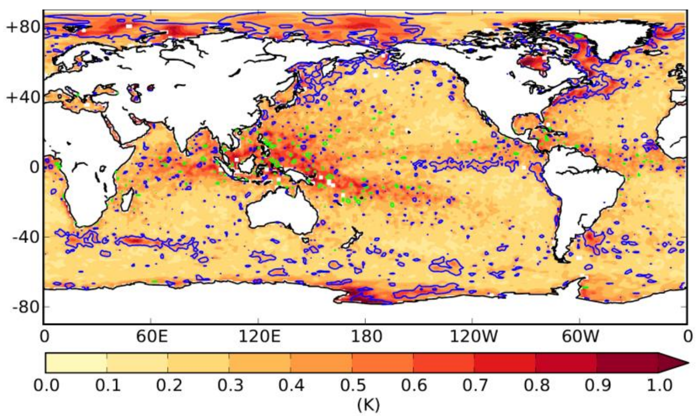
- biases in the model

model adjustment:

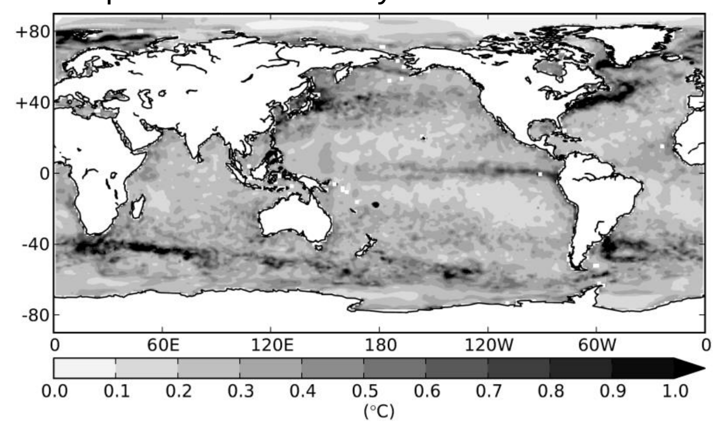
- assimilation switch-off
- imperfections in the CERA initialisation

Error in the coupled forecasts initialised by UNCPL analysis (with the full SST coupling)

1000hPa temperature RMSE after 12 hours versus own analysis



RMS difference between the SST in the ocean and atmospheric UNCPL analysis



Blue contours +0.15 in RMSE

Green contours -0.15 in RMSE

Initial shocks linked to unbalanced analysis

SST differences in the UNCPL analysis produce larger

D. Mulholland, P. Laloyaux, K. Haines and M. Balmaseda. Origin and impact of initialisation shocks in coupled atmosphere-ocean forecasts. Monthly Weather Review, In Press, 2016.

Improving the coupled assimilation system

A coupled atmosphere-ocean assimilation system has been developing at ECMWF with promising results

- quality of coupled analysis
- use of near surface observations
- initialisation of coupled forecasts

ECMWF Roadmap to 2025

“As ECMWF’s forecasts progress towards coupled modelling, interactions between the different components need to be fully taken into account, not only during the forecast but also for the definition of the initial conditions of the forecasts.”

Coupled data assimilation is a relatively new field of research

- many questions are still open, future directions might evolve as experience is gained
- biases between the different Earth system components are another important aspect that might prove very important in practice (Ozone example, J. Flemming)
- research efforts towards models bias correction in the coupled data assimilation context will be necessary

Summary and discussion

- To first order, metrics for coupled systems should be the same as for uncouple, e.g., for SST, Sea level, winds, T2m, …
- Need diagnostics to evaluate impact of coupling: observation impact across media, co-variability, closure of budgets, initialization shock.
- Particular focus on tropics, tropical cyclones, and impact of interactive sea-ice.
- Need metrics to assess impacts of coupling on a process level: surface fluxes, surface stresses, roughness, …
- Need metrics to measure pumping of heat and moisture to the upper troposphere.