

# The ECMWF coupled data assimilation system for climate reanalysis

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Acknowledgement: Eric de Boisseson, Per Dahlgren, Dinand Schepers, Yuki Kosaka, Sami Saarinen, Paul Poli, Hans Hersbach, Shoji Hirahara, Manuel Fuentes, Kristian Mongensen, Linus Magnusson, Elias Holm, Massimo Bonavita, Magdalena Balmaseda, Adrian Simmons, Dick Dee, Roberto Buizza



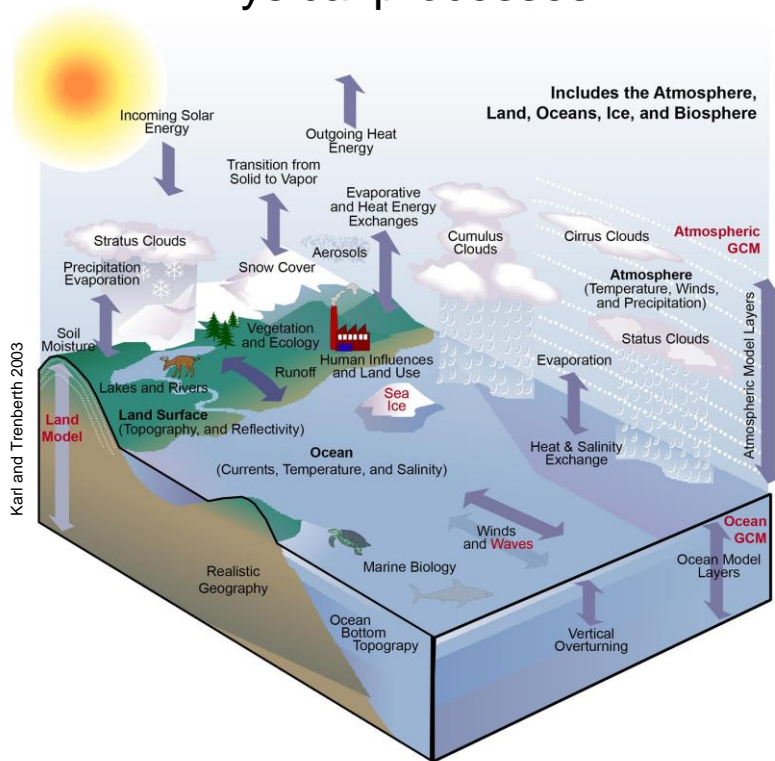
# Outline of the talk

- Implementation of the coupled assimilation system (CERA)
- Extended climate reanalysis

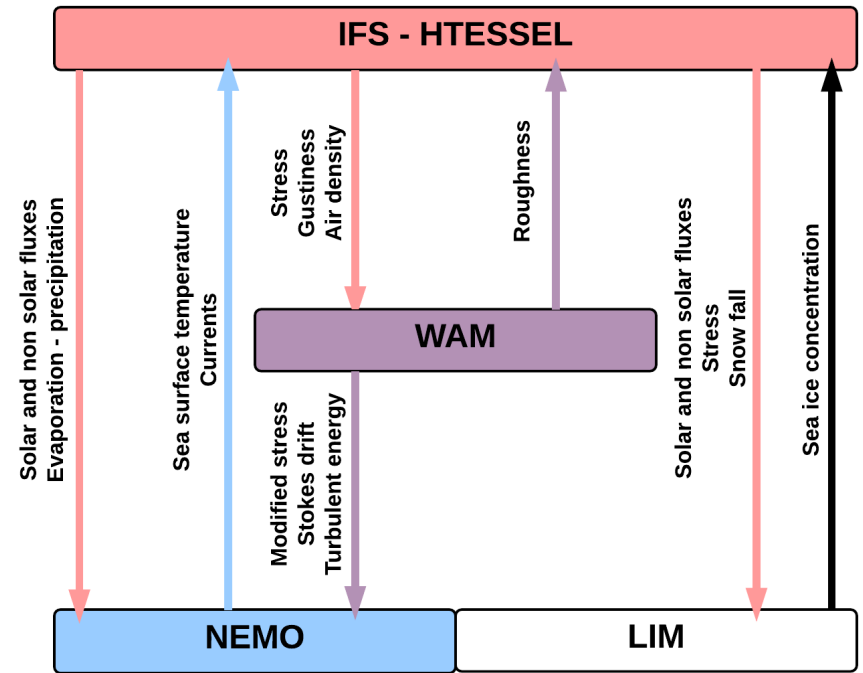
# Weather prediction at ECMWF

An earth system approach with advanced modelling techniques

## Physical processes



## Coupled earth system model



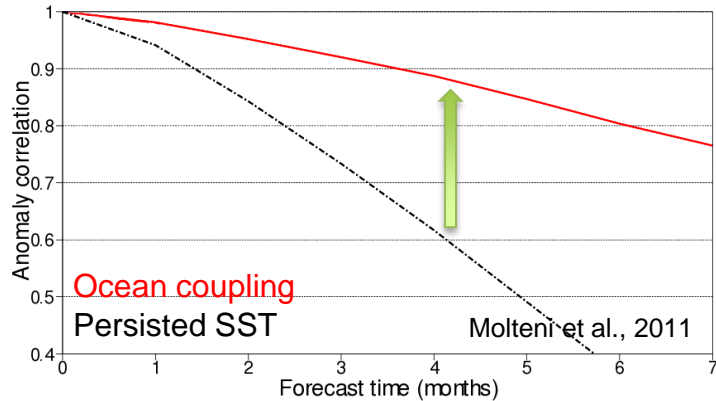
This coupled model is used for the following systems:

- the ensemble prediction system (ENS) from day 0 to 15 and the monthly extension
- the seasonal forecasting system

# Importance of the ocean coupling for weather prediction

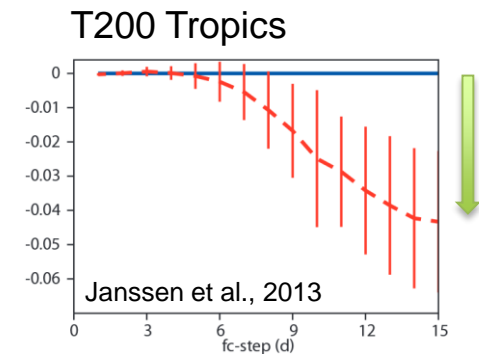
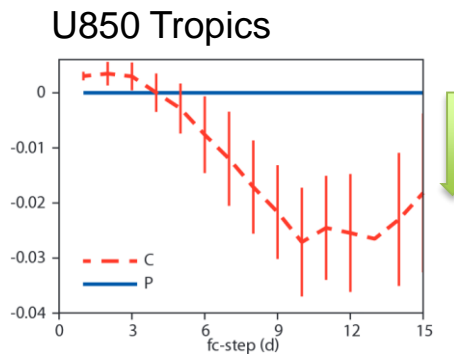
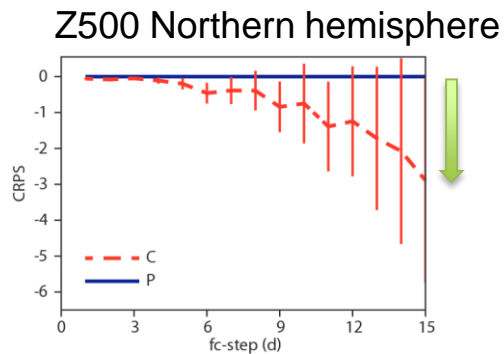
## For seasonal forecasting

SST anomaly correlation for NINO3 (360 dates, 1981-2010)



## For medium range forecasting

CRPS forecast skill score (61 cases in Jan–Aug 2012)

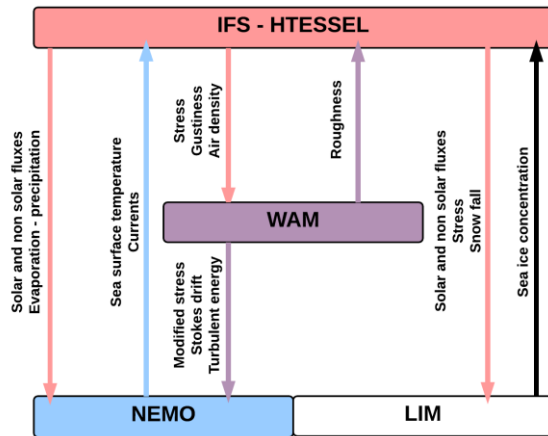


Atmosphere and ocean are coupled in forecasts, but atmospheric and ocean analyses are still computed separately using uncoupled models

# Coupled atmosphere-ocean assimilation system (CERA)

A new coupled assimilation system has been developed:

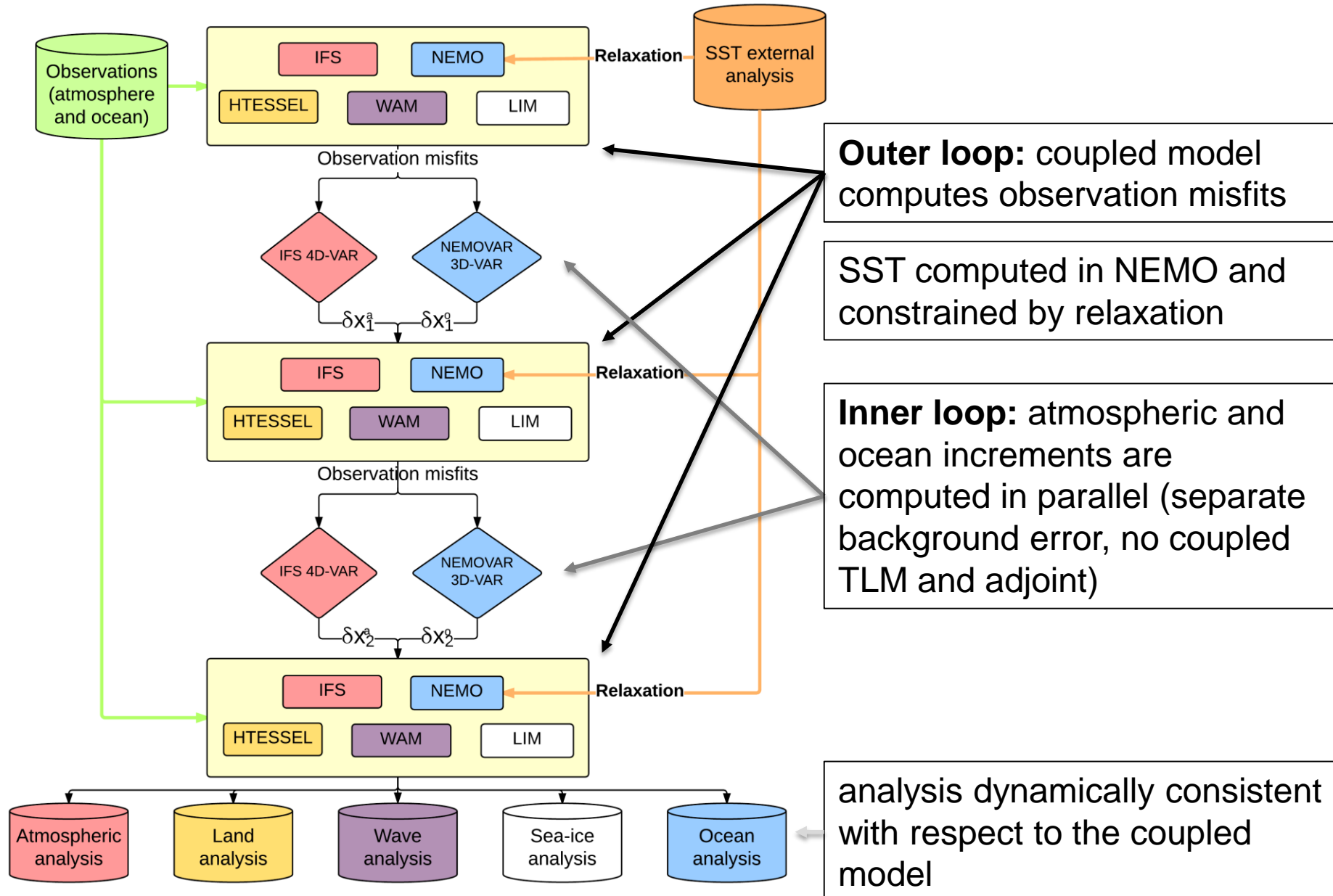
- the coupled earth model is used in the assimilation



- atmospheric and ocean observations assimilated simultaneously
- variational approach with a common 24-hour assimilation window

# Coupled atmosphere-ocean assimilation system (CERA)

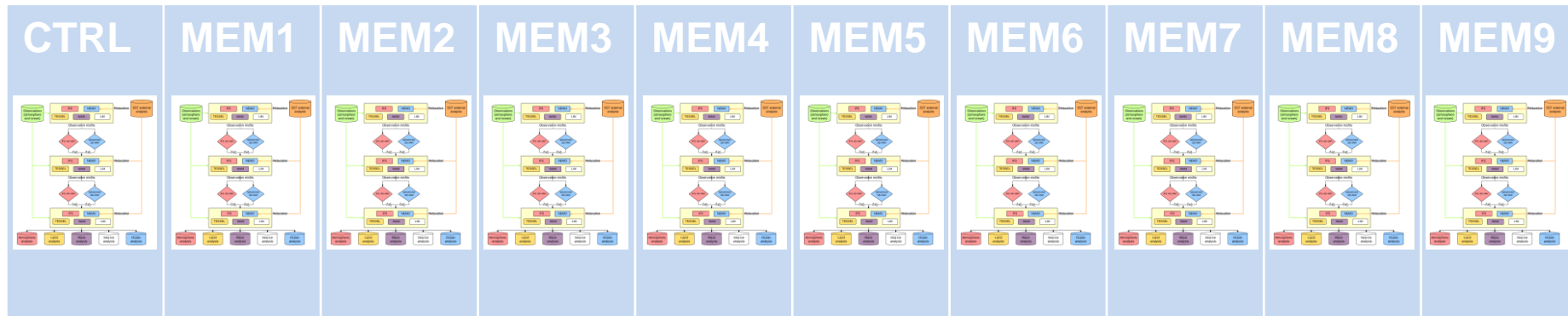
## Schematic for one assimilation cycle



# Coupled atmosphere-ocean assimilation system (CERA)

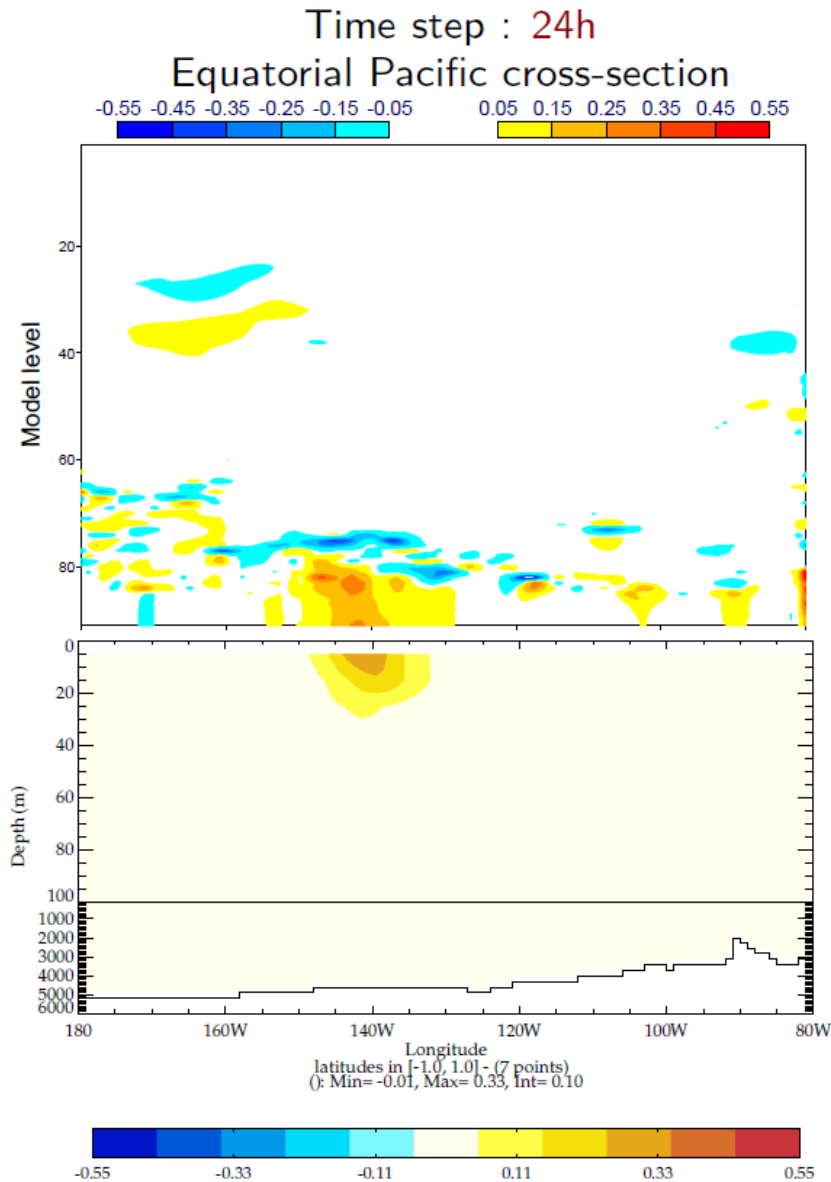
CERA implements a 10-member EDA system with perturbations:

- atmospheric and ocean observations
- perturbation in the sea surface temperature
- stochastic physics in IFS atmospheric model



→ hybrid method for the background error in the atmosphere, not yet in the ocean

# Information exchange in the CERA system



Atmosphere-ocean temperature cross-section

Ocean increment at the beginning of the assimilation window (one temperature observation at 5-meter depth)

→ The coupled model in the outer loop can successfully propagate information between the components

→ Ocean observations can impact atmospheric estimate

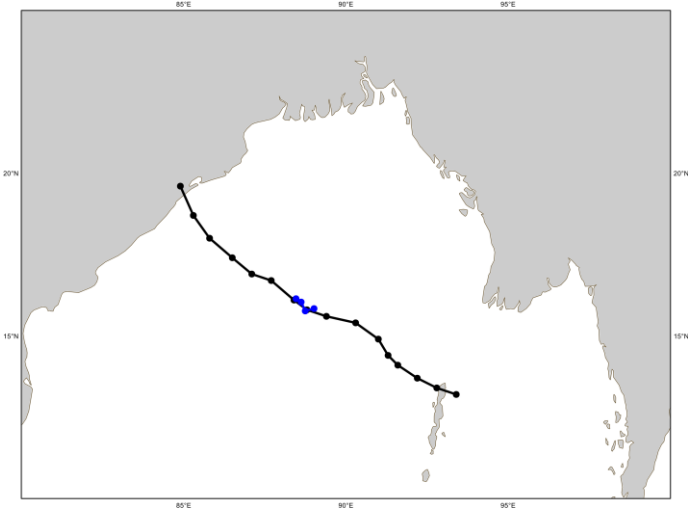
A coupled data assimilation system for climate reanalysis. P. Laloyaux, M. Balmaseda, D. Dee, K. Mogensen and P. Janssen. QJRMS, 142: 65–78, 2016.

Origin and impact of initialisation shocks in coupled atmosphere-ocean forecasts. D. Mulholland, P. Laloyaux, K. Haines and M. Balmaseda. MWR, 2016.



# CERA assessed for a tropical cyclone

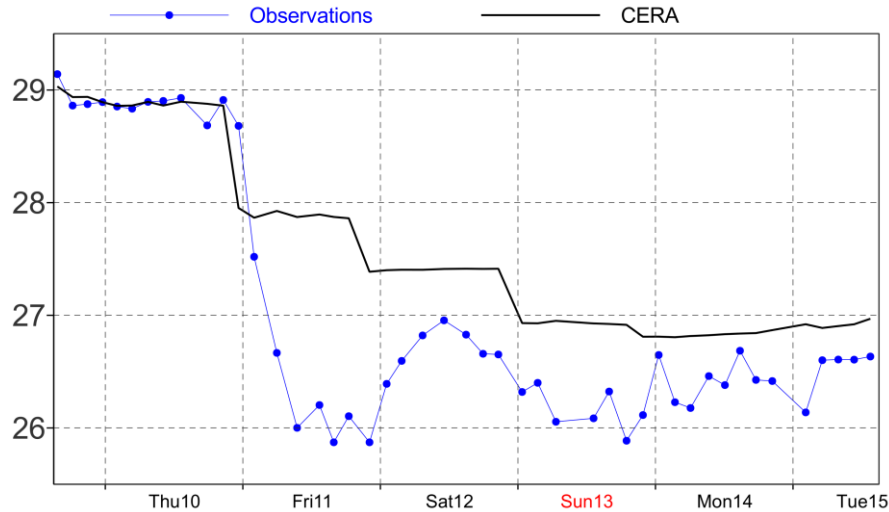
## Tropical cyclone Phailin (2013)



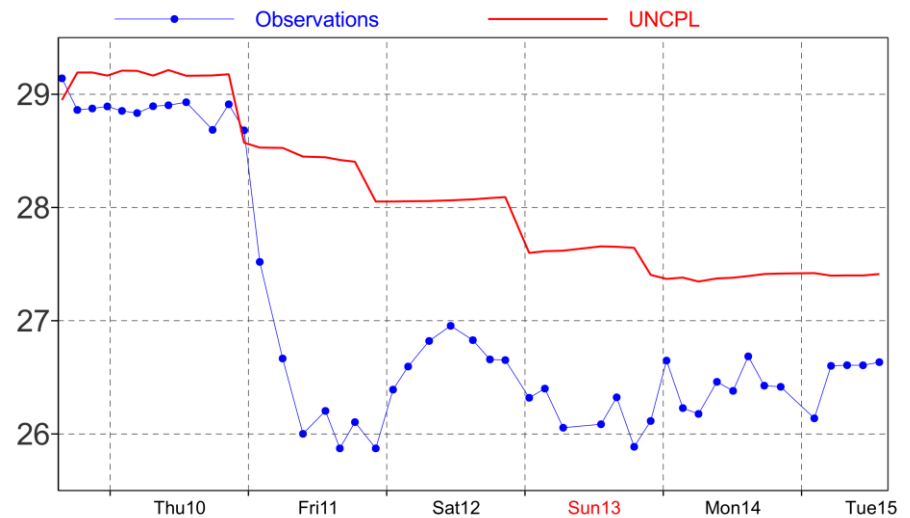
Coupled analysis is closer to the observations with a stronger cold wake

## Ocean temperature analysis at 40-meter depth

### CERA

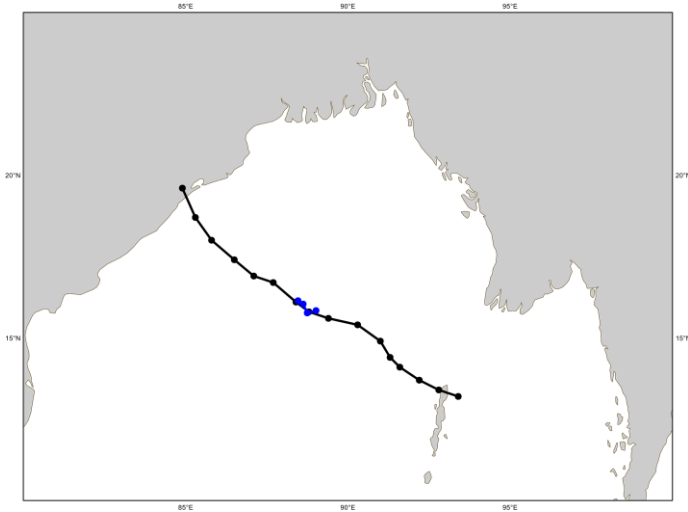


### UNCPL



# CERA assessed for a tropical cyclone

## Tropical cyclone Phailin (2013)



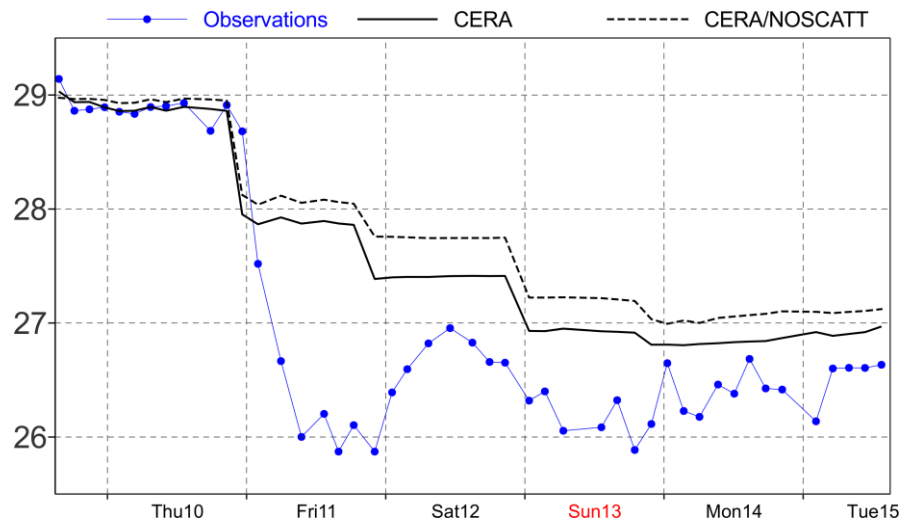
Coupled analysis is closer to the observations with a stronger cold wake

Crucial role of scatterometer data to estimate the ocean state in coupled assimilation

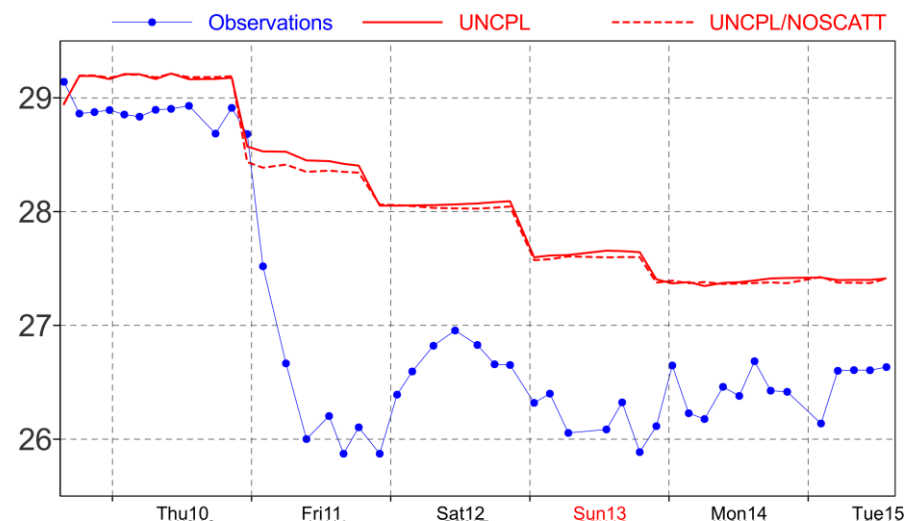
Impact of scatterometer surface wind data in the ECMWF coupled assimilation system. P. Laloyaux, J-N Thépaut and D. Dee. MWR, 2016

## Ocean temperature analysis at 40-meter depth (no scatterometer in dashed)

CERA



UNCPL



# Outline of the talk

- Implementation of the coupled assimilation system (CERA)
- Extended climate reanalysis

# Extended climate reanalysis at ECMWF

Activity started in 2011 (ERA-CLIM and ERA-CLIM2)

- reconstruct the past weather and climate spanning a period of 100+ years
- focus on consistency and low-frequency climate variability

**ERA-20C**: the first ECMWF atmospheric reanalysis of the 20<sup>th</sup> century



*Atmosphere*



*Land*



*Wave*

**Model:** IFS (CY38R1, Jun 2012)

**Forcing:** SST/SIC prescribed (HADISST2)

**Observation:** surface pressure and marine winds

**Assimilation:** 4D-Var

**Resolution:** 125km (T159L91)

**Period:** 1900-2010

# Extended climate reanalysis at ECMWF

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**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 pressure, marine wind, salinity and temperature profiles

**Assimilation:** new CERA system (10-member ensemble coupled DA)

**Resolution:** T159L91/ORCA1 Z42

**Period:** 1901-2010

## Computation footprint

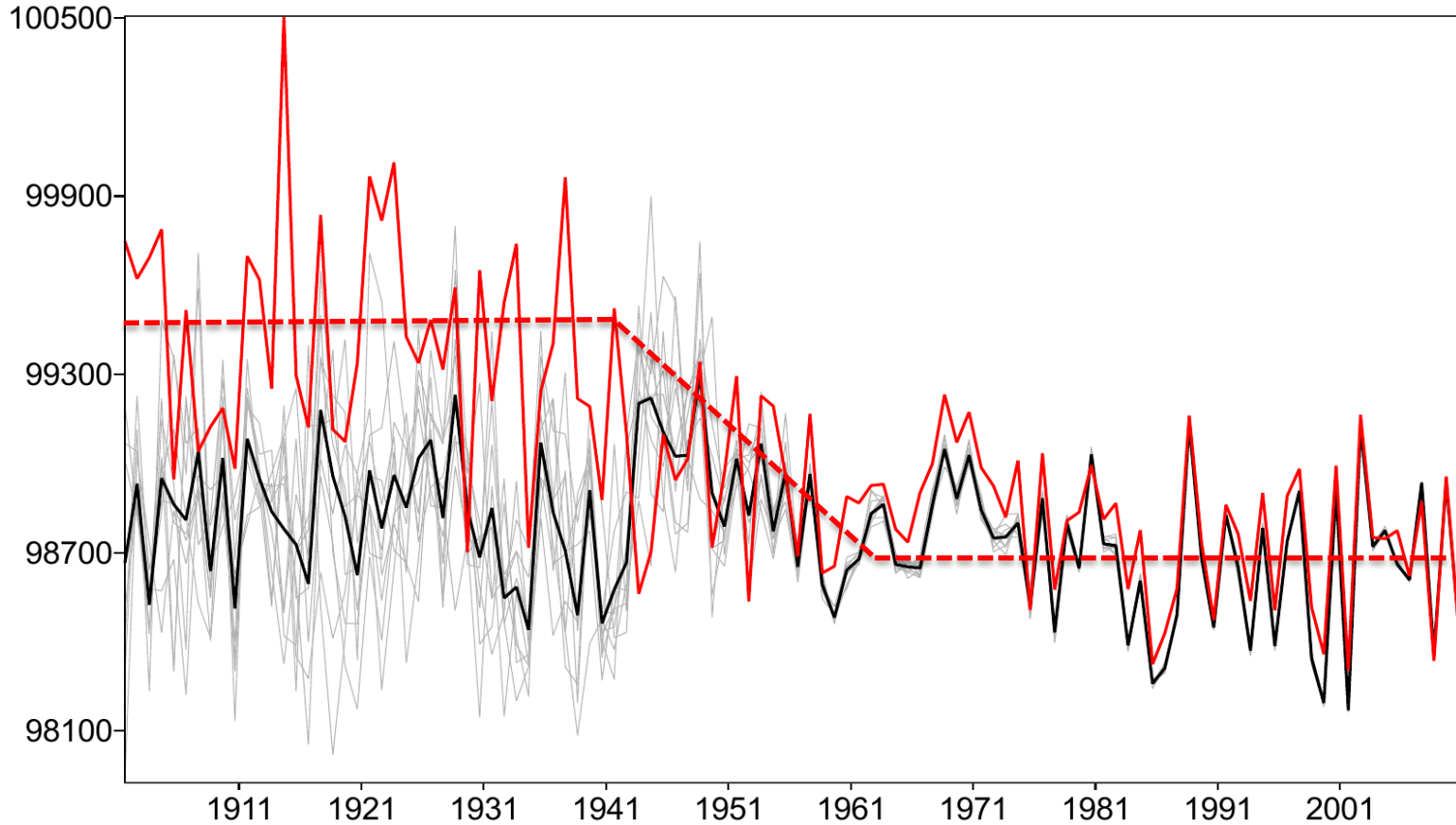
7 months of production using 20,000 cores

500,000 4D-Var problems to solve

1600 Tb of data

# Preliminary results of CERA-20C

MSLP analysis in CERA-20C (black) and in ERA-20C (red) over Antarctica for the SON period



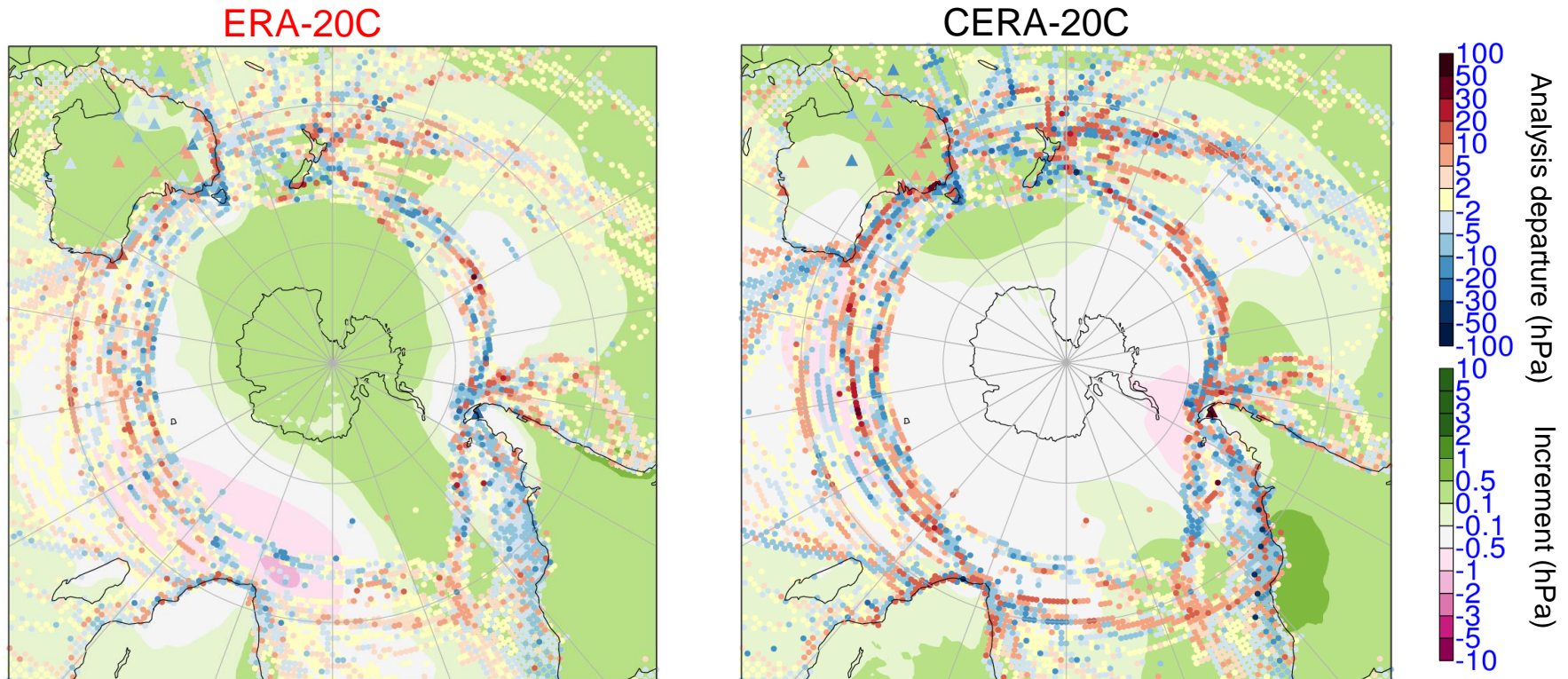
→ spurious trend in ERA-20C (8hPa higher before 1940) corrected in CERA-20C

# Preliminary results of CERA-20C

Observation error specification has been reviewed

- ERA-20C: from operations, inflated by a factor of two and kept constant
- CERA-20C: from the Desroziers' diagnostic on ERA-20C feedback information, time-varying (P. Poli et al., ERA-20C Deterministic, ERA Report Series, 48, 2015.)

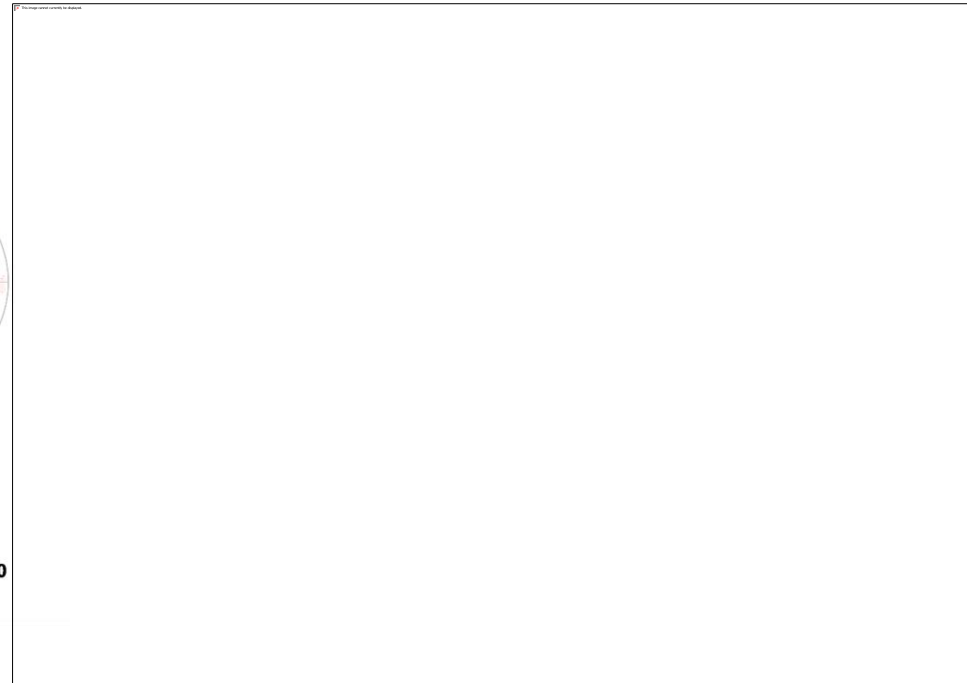
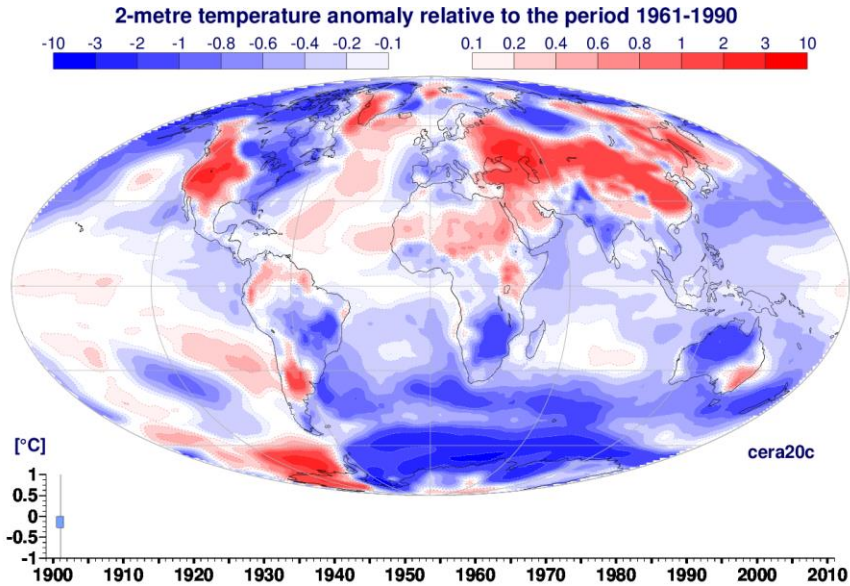
MSLP mean increment for the year 1924 (green positive increment, pink negative increment).



ERA-20C overfits the observations (too small observation error), hence producing large positive increments over Antarctica and wrong MSLP trends

# Preliminary results of CERA-20C

2-metre temperature anomaly (left) and upper-ocean heat content anomaly (right) in the control member





# Conclusions and future steps

Earth system approach looks promising, but coupling might transfer biases instead of positive feedback

Evaluation of CERA-20C is ongoing: assessment of hybrid EDA, ocean coupling, impact of ocean observations, climate trends, ...

CERA-20C dissemination is scheduled for the end of 2016

The screenshot displays the ECMWF website interface. On the left, a navigation menu includes 'Research homepage', 'Data Assimilation', 'Modelling and prediction', 'Climate reanalysis', 'Reanalysis datasets', 'Coupled Earth-system reanalysis', 'Reanalysis for climate monitoring', 'Ocean reanalysis', and 'Projects'. The main content area is titled 'Browse reanalysis datasets' and contains a table with columns for Dataset, Archive, Time period, Atmosphere, Atmospheric composition, Ocean waves, Ocean sub-surface, Land surface, Sea Ice, and Observation Feedback Archive. The table lists various datasets such as ERA-Interim, ERA-20CM, ERA-20C, ERA-20CL, ERA-40, ERA-15, ORAS4, ORAP5, and ORAS5, along with their respective time periods and availability for download.

Dataset	Archive	Time period	Atmosphere	Atmospheric composition	Ocean waves	Ocean sub-surface	Land surface	Sea Ice	Observation Feedback Archive
<a href="#">ERA-Interim</a>	<a href="#">Download</a>	1979-present	✓		✓		✓		Expected soon...
<a href="#">ERA-Interim/Land</a>	<a href="#">Download</a>	1979-2010					✓		
<a href="#">ERA-20CM</a>	<a href="#">Download</a>	1900-2010	✓		✓		✓		
<a href="#">ERA-20C</a>	<a href="#">Download</a>	1900-2010	✓		✓		✓		✓
<a href="#">ERA-20CL</a>	Expected soon...	1900-2010					✓		
<a href="#">ERA-40</a>	<a href="#">Download</a>	1957-2002	✓		✓		✓		
<a href="#">ERA-15</a>	<a href="#">Download</a>	1979-1993	✓				✓		
<a href="#">ORAS4</a>	<a href="#">Download</a>	1958-2015				✓			
<a href="#">ORAP5</a>	<a href="#">Download</a>	1979-2013				✓		✓	
<a href="#">ORAS5</a>	Expected soon...					✓		✓	

On the right, the 'ERA-20C, Daily' data selection interface is shown. It includes a 'Type of level' dropdown menu (set to Surface), a 'Type' dropdown menu (set to Analysis), and a 'Select date' section with a date range from 1900-01-01 to 2010-12-31. Below this is a 'Select a list of months' section with a grid of years from 1900 to 1930 and months from Jan to Dec, allowing for the selection of specific data points.

The CERA system is currently implemented at higher resolution with upper-air and satellite assimilation

- atmosphere from T159 to T399
- ocean from 1 degree (42 levels) to ¼ degree (75 levels)