NCMRWF Coupled Ensemble Extended Range Prediction (ERP) System


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Outline

1. Stand-alone Ocean Model, ODA (NEMO)

2. Coupled System: Short, Extended

3. Skill of ERP

4. Examples of Ensembles

5. Summary
The Multiple Time Scales of Climate

Weather
- MJO/monsoon bursts
- Annual cycle
- El Nino/La Nina
- Decadal Variability
- Climate Change

Development & Implementation of a Seamless Modelling System is the Key
Model Development Cycle is Fast
NCMRWF Unified Model (NCUM) and Data Assimilation System
Seamless Modelling System: Fast Model Development Cycle

- **330-m Delhi Model**
  - (36 hrs forecast based on 00 UTC)

- **1.5-km Regional Model**
  - (48 hr. forecast based on 00 UTC)

- **4-km Regional Model**
  - (72 hr. forecast based on 00 UTC)

- **12-km Global Model**
  - 10 Day forecast based on 00 & 12 UTC

- **Global Ensemble Prediction System (NEPS)** –
  - (12-km 11+1 members, 10 Day forecast based on 00 & 12 UTC)

- **Regional NEPS**
  - (4-km/12 members, 3 Day forecast based on 00 UTC)

- **Coupled Model (60 km)**
  - (NCUM+JULES+NEMO+CICE)
  - (2 weeks/1Month/Season)

Seamless Model Best suited to investigate the multi-scale Tropics/Monsoon
Global ODA NEMOVar

- Model: Global NEMO
- Model Time step: 20 minutes
- Assimilation Technique: 3DVar FGAT
- Assimilation window: 24 hrs
- Observed Data: Temperature, salinity, SLA, Sea Ice
- Surface boundary forcing: NCUM Winds at every 1 hrs
  Fresh water fluxes (Precipitation and Snow fall)
  Radiation fluxes (Net LW and Net SW) every 3 hrs
Ocean Data in ODA in NEMOVar

ARGO Floats: T and S profiles up to 2000 mts
Moored Buoys: Surface Met. Ocean Parameters
Drifters: Surface Met. Ocean Parameters
XBT Lines: T Profile in shipping Routes
Current Meter Array: Ocean currents at various depths
Tide Gauges: Sea level
Research Vessels: AWS, Upper Ocean parameters, XBT, ADCP

Satellite Data: Sea Surface heights, Sea Surface elevation (Jason-2 / 3, SARAL AltiKa)
SST, Sea Ice (MW)
Via Atmos Model Assim: Ocean surface wind Vectors, Surface Fluxes
Role of Ocean: Coupled NWP, ERP/Seasonal, Inter-Annual Prediction

Ocean & Sea-Ice Data Assimilation System

NEMO Ocean Model & DA System
Data Coverage: Satellite SST (AVHRR + METOP); 20190219

Number of Observations: AVHRR (92596) METOP (612285)
Data Coverage: Surface Observations; 20191220

Number of Observations: SHIP(2287) MOORED(19548) DRIFTER(35323)
Data Coverage: Profile Observations; 20191220

Number of Observations: XBT(4) TESAC(63) MOORED(262) ARGO(433)
Cryosat-2

Jason-2
Data Coverage: Sealce Observations (NH+SH); 20191220

Number of Observations: NH(395194) SH(510843)
Monsoon 2019
More freshwater in NEMO analysis than RAMA buoy
Spreading freshwater from northern BoB to the coastal region & central BoB
BoB Surface Currents: Global NEMO and NIOT HF RADAR
Heat Content 80m depth ($x10^6$ J/m$^2$)
(AS; 5-15N)

From Real-Time NCMRWF NEMOVar Analysis 2017
Arabian Sea Warm Pool
(66-72E; 5:15N)
Observed TCHP from Global Ocean Data Assimilation System: NCMRWF

Trop. Cyclone FANI
Impact of Altika derived SLA on assimilation system
Expt August 2013

Sea Level Anomaly (m)

(a) OBS

(b) FG

(c) FG–OBS

(d) IAU

(e) IAU–OBS
- GODAS mean MLD bias is deepening from Summer monsoon to winter monsoon with respect to ARGO analysis.
- NEMO mean MLD negative bias ~5m.
Mean number of ARGO floats for Temperature and Salinity during 2016-19
Model Control Run

March–April–May

$1^\circ \times 1^\circ$ L75 Global NEMO

NIO/CSIR Climatology

Bias SST

Bias SSS

Bias MLD

Bias D20
NCMRWF Ocean Forecast Verification for May–2017

Surface Current (m/s)

(a) day1–bias  
(b) day2–bias  
(c) day3–bias  
(d) day5–bias  
(e) day7–bias
NCMRWF Ocean Forecast Verification for May-2017

Sea Surface Salinity (PSU)

Stand-alone NEMO Global Fcst
Stand Alone NEMO: Freshwater (less salinity) is captured well in Day-5, & Day-9 forecast.
Warm Layer at surface is well predicted in Day-5, & Day-9 forecast
Propagation of SSS during Monsoon 2019; Day-5, & Day-9 forecast are slightly weaker
35 psu salinity propagation average over 82-87E

Northward propagation of high salinity water from AS to BoB through SLD
Atmos NCUM

Coupler, OASIS

Ocean. NEMO 3.4

LS Model, JULES

Sea Ice CICE 4.3
HadGEM3AO based NCMRWF Global Coupled Model

Atmosphere : NCUM (N216) ~ 60 km horizontal
L85 (going up to 85 km)
50 levels are below 18 km

Ocean : NEMO 0.25 x 0.25
L75 (1 m near surface;
35 layers in upper 300 mts)

Sea-Ice : CICE Model of Los Almos Lab, USA
OASIS Coupler (CERFACS and collaborators)

Real-Time Coupled Runs up to 15 days daily

Real-Time Coupled Extended Range Prediction
(multi-week up to 4 weeks) runs once a week ; Now 16 members
Impact of Coupling

Day-7

AS(50–70°E, 5–15°N)

Day-9

Impact of Coupling

Day-7

AS(50–70°E, 5–15°N)

Day-9
JAS 2017: Improvement in Upper Ocean SST
JAS 2017: Improvement in Upper Ocean SSS
Extended Range Predictions with NCMRWF Coupled Model

- NCMRWF Coupled Model Runs with 60 km (NCUM) and 25 km (NEMO)
- **Model Climatology**: 23 years (1993-2015) Hindcast data used
- **Ensemble Strategy**: lagged ICs + stochastic physics
- **7 members hindcast**: Hindcasts initialized on 1st, 9th, 17th & 25th of each month.
- **16 Members forecast**: 4 members per day. 4-startdates.
- **Stochastic physics scheme**:
  - Stochastic Kinetic Energy Backscatter scheme of Bowler et al., 2009 is used to represent unresolved processes and provide small grid-level perturbations during model integration.
- Nearest hindcast date is used to compute weekly anomalies
Mean Monsoon Rainfall Bias
Week 1 to 4

17 year (1998 to 2015) mean JJAS rainfall (mm/day) from (a) observations and (b) model
Bias in forecast for (c) week 1 (d) week 2 (e) week 3 and (f) week 4
Spatial variability of anomaly correlation of rainfall over different homogenous regions over India for 23 years of hindcast for weeks 1 to 4 forecasts.
Inter-annual rainfall anomalies averaged over latitudes and longitudes 75°E to 82°E for obs (row 1), week1 (row 2), week2 (row 3), week3 (row 4) from obs and forecast.
Wet to Dry and Revival: Forecast issued on 19th July 2018

Weekly obs anom of rainfall (mm/day) between 20 July to 16 Aug 2018

Weekly NCMRWF Coupled Model anom of rainfall (mm/day) between 20 July to 16 Aug 2018; Fcst issued on 19 July 2018; up 3 weeks model Fcst is quite reasonable
Active Monsoon was well captured 3 weeks in advance
Weekly Forecast verification of Rainfall anomalies (12-18 July 2019) (CNCUM)

Break Condition is well captured 4 weeks in advance
Delayed Onset Monsoon 2019 from Real-Time NCMRWF Multi-Week (Extended Range) Forecast System: GC2 N216

NCMRWF CNCUM Experimental Extended Range Forecasts—20190516
Precipitation (mm/day)

Anom Fcst from 23 years Hindcast for 4 start dates per month, for all 12 months
Weekly Forecast verification of tmax anomalies for 17_23Jan2020 (NCEP-CFS)

Weekly Forecast verification of Tmax anomalies (17_23Jan2020)(CNCUM)
Weekly Forecast verification of tmin anomalies for 17_23Jan2020 (NCEP-CFS)

Weekly Forecast verification of Tmin anomalies (17_23Jan2020)(CNCUM)
Week-1 and Week-2 Ocean Forecasts from NCMRWF Coupled Model
Movement of High Saline Water into BoB
Sea Surface Temperature (°C) IC: 20200205

(a) Mean Week-1 Fcst

(b) Spread Week-1 Fcst

(a) Mean Week-2 Fcst

(b) Spread Week-2 Fcst

IC: 05Feb2020
Increasing SST trend

IC: 05Feb2020
Increasing SSS trend

Coupled Forecast Based on 05FEB2020 IC

SSS
Surface Current (m/s), EnsMean(Vector) and Spread(Shaded) IC=20200205

(a) Week-1 Fcst → 1.50 m/s
(b) Week-2 Fcst

IC: 05Feb2020
1993-2015, 23 yrs, 23 yrs x 6 ens = 138 sample
Black line Obs mean GPCP

Light shade: Range of 138 forecast sample
Darker shade: Range of 6 members (mean forecast)

Range and Mean of Climatological Forecasts

Range and Mean of Obs Rainfall
May-September
Sample size: 380
(19_years*4_times_monthly*5_months)

Spread and RMSE (6-member hindcasts)

Spread for each month,
sample size: 92 (23*4)
SD of 138 samples (forecasts)
2019 JJAS. Rainfall (mm/day) 
mdd weekly Obs 

Monsoon Rainfall
Week-2 Forecast issued on 18Jul2019
IC: 15,16,17 July
Validity: 26th July-1st August

Model Mean

Model Rainfall, different members

Observation
Week-2 Forecast issued on 18Jul2019
IC: 15, 16, 17 July
Validity: 26th July-1st August

(Model_Member – Model_Mean)
Week-2 Forecast issued on 24Jan2020
IC: 19,20,21,22 Jan x 4 = 16 Mem
Validity: 31st January – 6th February

Western Disturbance (WD)
Model Rainfall, different members

Observation (IMD-Gridded)

Model Mean
Week-2 Forecast issued on 24 Jan 2020
IC: 19, 20, 21, 22 Jan x 4 = 16 Mem
Validity: 31st January – 6th February

(Model_Member – Model_Mean)
NCMRWF Coupled Model Runs with 60 km (NCUM) and 25 km (NEMO)
Experimental Seasonal Forecast

- Number of Forecast members: 40
- Startdates: 16th to 23rd May 2019; 5 member per startdate
- Number of hindcast members: 23 years*6 per year (1993-2015)
- Bias is computed from merged rainfall dataset.
- Bias corrected forecast is included.
- Hindcasts are used to defined the normal for percentage departures
- Hindcasts are used to define threshold for tercile categories for probabilistic forecasts
- All spatial plots in mm/day. All t-series plots mm/season (JJAS)
- Standard analysis of temporal/pattern correlations included
- Model picked the correct sign 15/18 times during 1998-2015
Hindcast: 1998-2016

Monsoon (JJAS) Rain in mm

ECMWF

UKMO/GS5

S+G
Inter-annual variability of JJAS rainfall over Indian Landmass

JJAS rainfall

NCMRWF GC2 N216 Hindcast runs

JJAS rainfall anomaly
JJAS 1998-2016 Anomaly Correlations

UKMO GS5 GC2

ECMWF

NCMRWF GC2 N216 → 1998-2016 Hindcast

2019 seasonal Monsoon Fcst provided to IMD in April/May
Forecasts for Polar Regions

Arctic & Antarctic

1) Daily up to 15 days
2) Once a week up to 4 weeks
Arctic Sea Ice/Ocean Parameters
Early simulations Data of Reg. Coupled Model: From Huw and colleagues at MO

Rainfall close to Landfall Days looks more realistic

24 hr Total Rain (mm/d) Comparison valid on 03Z27 Apr 2019
ECMWF coupled MRF IFS (9 km) Coupled to NEMO Ocean (25 km) & WAM wave

Ocean coupling in tropical cyclone forecasts
KRISTIAN S. MOGENSEN, LINUS MAGNUSSON, JEAN-RAYMOND BIDLOT, FERNANDO PRATES

Sea-surface temperature
To verify whether the ocean response to the tropical cyclone forcing described above is realistic, we have compared the predicted SST to observations from drifting buoys and ships. Figure 3 shows the SST in 5-day coupled small number of available observations. The opposite holds true for Neoguri, where we find a strong cold wake east of the track in the coupled forecast, where the cooling reaches 5°C. The SST in the coupled forecast is in good agreement with the two observations inside...
Preparing for Exascale
It’s not all about the dynamical core!

Data Assimilation, Observations, Ensembles

Big data & I/O

Coupling

LFRic/GungHo

NEMO Ocean

UKCA

JULES
Coupled Modelling and Initialisation: NCMRWF Status

1. Global Ocean Data Assimilation running real-time
   (NEMOVar 25 km L75 daily on CRAY HPC; with stand-alone global NEMO forecast up to 10 days)

2. Global Coupled daily 15 days (MRF) runs on IBM HPC
   (For developing Coupled NWP ultimately)
   Currently coarse atmosphere N216 GC2; 10 km atmosphere being tested

3. Extended range (multi-week) real-time currently N216 atmosphere
   Up to 4-weeks now being run once a week, 16 ensemble, Global GC2 [CRAY HPC]

4. Seasonal tested and implemented
   (experimental Monsoon2019 forecast runs from Apr/May start dates done)

5. Regional 4 km high resolution coupled model for severe weather and process studies (being implemented)
Outstanding Issues

• How realistic is Ocean Analysis (Reanalysis)  
  (validation studies for Reanalysis data and Model simulations required)
• Meso-scale systems need to be validated both in analysis and Forecasts
• Surface, Sub-surface and satellite data enough there ?
• How fast the error grows in forcing fields from atmosphere model ?  
  (At scale from Days-to-Season; Link to IOD and BoB)
• Can we separate/quantify errors developing in Ocean Model due to 
  (i) atmosphere forcing  (ii) the ocean model itself ?
• Assimilated chlorophyll ( and Dust , Aerosol) information into Modelling System?
• If coupled assimilation and coupled model will be better  ?
• We need sufficient field campaign data in phased manner across seasons.
Summary & Plans

1. At NCMRWF N216 GC2 system along with NEMOVar ODA has been implemented and are being run in real-time for MRF (15 days daily) and ERP (Multi-week up to 4 weeks once a week).

2. A stand alone NEMO global model is also being run for 10 days (daily).

3. Verification of NEMOVar system for Indian Ocean, Stand-alone NEMO and coupled NEMO (at 15 days scale) is being carried out.

4. Verification of hindcast for the ERP (multi-week) system is also being carried out for summer monsoon and winter seasons.

5. Few runs at seasonal scale for summer monsoon with Apr/May start dates have been completed. Will be made real-time this year.

6. Sea-Ice verification for Polar Regions are also being carried out in days-to-season scale from these runs.

7. NCMRWF is in the process to migrate to Higher resolution of coupled model for ERP.
Way Forward

• Coupled Global NWP (10 km ?)
  Regional Coupled system 1.5 km
  (Include details of Regional Seas, LS interactions)
  Improving Norther Bay Coupled Process
  Improve Real-Time Obs in Northern Bay

• Global Coupled Data Assimilation

• Higher Resolution Global Coupled system for S2S
  (with more ensemble numbers)

• Development of applications based on probabilistic
  Prediction from EPS (Coupled)