ECMWF update:

SEAS5: configuration and evaluation
Reanalysis: era5

Laura Ferranti
Advantages
– Confidence on representation of relevant processes
– Possibility of Seas results influencing the extended range.
– Simplicity

Trades off:
– Certain aspects of the initialization
– Slowing the inclusion of new earth-system components (such as O3).

SEAS5 Innovations
– More recent model cycle.
– High resolution (ocean and atmosphere).
– Sea-Ice
– New ocean reanalysis ORAS5
**SEAS5 components:**

<table>
<thead>
<tr>
<th></th>
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<tbody>
<tr>
<td>Atmosphere</td>
<td>Cycle 36r4 TL 255 L91</td>
<td>Cycle 43r1 TCo 319 L91</td>
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<tr>
<td>Ocean</td>
<td>NEMO v3.0 ORCA 1.0-L42</td>
<td>NEMO v3.4 ORCA 0.25-L75</td>
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<tr>
<td>Sea ice model</td>
<td>Sampled climatology</td>
<td>LIM2</td>
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<tr>
<td>Non-orographic GWD</td>
<td>Altered</td>
<td>Altered</td>
</tr>
<tr>
<td>Ozone scheme</td>
<td>Cariolle</td>
<td>BMS</td>
</tr>
<tr>
<td>Ozone interactive</td>
<td>Yes</td>
<td>No</td>
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</tbody>
</table>

**SEAS5 vs. SEAS4**

- Updated IFS cycle with many improvements to model physics
- Increased horizontal resolution in atmosphere and ocean, increased vertical resolution in the ocean
- Introduction of the LIM2 interactive sea ice model
- Ozone scheme non-interactive

**ERA5 forcings adopted for SEAS5**

- Decadally varying tropospheric sulphate aerosol from CMIP5
- Time varying stratospheric volcanic aerosol from GISS
- GHG forcings from CMIP5 as in 43r1
### Initialization and forecast strategy

<table>
<thead>
<tr>
<th></th>
<th>SEAS4</th>
<th>SEAS5</th>
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<tr>
<td>Atm. Initialization</td>
<td>ERA-Interim</td>
<td>ERA-Interim</td>
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<td>Land initialization</td>
<td>ERA-Interim Land 32r3</td>
<td>ERA-Interim Land 43r1</td>
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<td>Ocean initialization</td>
<td>ORA-S4</td>
<td>ORA-S5</td>
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<td>Ensemble spread</td>
<td>SPPT &amp; SKEB</td>
<td>SPPT &amp; SKEB</td>
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<td>Forecast members</td>
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<tr>
<td>Reforecast members</td>
<td>15</td>
<td>25</td>
</tr>
<tr>
<td>Calibration period</td>
<td>1981-2010</td>
<td>1993-2015</td>
</tr>
</tbody>
</table>

**SEAS4 vs. SEAS5**

- Updated ocean and land initial conditions
- Updated atmosphere and ocean initial condition perturbations
- Larger reforecast ensemble size
- Calibration period set by C3S
Global SST biases improve, especially in the ENSO regions

Particular improvement in the ENSO regions, much better foundation for ENSO teleconnections
Global SST biases improve, especially in the ENSO regions

![NINO3.4 mean absolute SST graph]

ENSO SST drift improves markedly. Also a small increase in ENSO correlation scores, an improvement in ENSO variance, and a decrease in RMS error.

![Graphs showing improvements in SST and correlations]
Stratospheric temperature and winds biases increase

SEAS4 – ERAI (DJF)

SEAS5 – ERAI (DJF)

Stratospheric temperature and winds biases are large in both models, but SEAS5 is worse.

Particular concerns about the midlatitude jets and the polar vortex degradation since SEAS4, which remain despite adjusting GGAUS.
SEAS5 improvement in sea ice and high-latitude skill – summer forecasts

Jul forecasts of ASO area-mean t2m north of 70N

ACCD = 0.34
ACCD = 0.67

vertical bars: inter-quartile range of ensemble

ACCD = correlation between forecast and ERA-I anomalies w.r.t. the linear trend

- SEAS4 sea-ice: climatology of last 5 years
- SEAS5 sea ice: prognostic with LIM2

SEAS5 clearly outperforms SEAS4 in summer for both sea-ice extent and 2m temperature. Positive contribution of prognostic sea ice to improved 2m temperature forecasts highly likely (to be investigated further).

From: Steffen Tietsche
Steffen.Tietsche@ecmwf.int
SEAS5 loss of DJF surface temperature skill over parts of the North Atlantic

SEAS4

SEAS5

North Atlantic DJF SST anomalies

ROC skill score, DJF t2m in lower tercile, hindcasts Nov 1981-2015
Loss of skill, calibration, and nonstationary SST bias

1981 - 1995

2000 - 2015

- All scores for SEAS are calculated on calibrated data (bias removed)
- SEAS4: stationary cold bias → forecasts can be calibrated
- SEAS5: strong warm bias before year 2000, little bias after → calibration fails, no apparent

DJF SST forecast bias (K) for Nov initialization
DJF SST in “no-skill” box for November initialization

Time series of forecast ensemble means and ERA-I verification

(correlation with ERA-I anomalies)

SEAS4:
• constant cold bias of ~1.5K
• both year-to-year and long-term variability well captured

From: Steffen Tietsche
Steffen.Tietsche@ecmwf.int
DJF SST in “no-skill” box for November initialization

Time series of forecast ensemble means and ERA-I verification (correlation with ERA-I anomalies)

SEAS5:
- warm bias of ~2 K before 2000, little bias afterwards
- prediction of year-to-year variability okay, but decadal signal wrong

From: Steffen Tietsche
Steffen.Tietsche@ecmwf.int
DJF SST in “no-skill” box for November initialization

Time series of forecast ensemble means and ERA-I verification (correlation with ERA-I anomalies)

Sensitivity experiment #2: high-resolution ocean, but initial conditions from ORAP5
- Similar to SEAS5, but reduced bias in the 1990s → problem present, yet slightly better

Conclusion so far: problem lies in the high-resolution initial conditions (ORAS5/ORAP5)

From: Steffen Tietsche
Steffen.Tietsche@ecmwf.int
Atlantic ocean heat transport and SST relaxation

ORAS5 before 2000 has two compensating errors:
1) too high northward ocean heat transport
2) artificial heat removal via SST nudging (~300 W/m²)
In the forecast, SST nudging abruptly disappears, but density-driven ocean circulation continues

Strong warm bias in SST and upper ocean heat content

From: Steffen Tietsche
Steffen.Tietsche@ecmwf.int
SEAS5

SEAS5 becomes operational on Nov 1, 2017, replacing System 4 which has been operational since 2011.

Scientific highlights

– Improved ENSO biases and scores.
– Improved 2m temperature skill in the tropics due to accumulated improvements in model physics.
– Inclusion of the LIM2 interactive sea ice model improves sea ice prediction skill.

Issues

– Skill over Europe is comparable to that in System 4. However, a new hole in skill is present in at the tip of the Gulf stream in the North Atlantic, where decadal variability is not captured.
– The hole is due to warm SST bias in early period that disappears around 2000. Sensitivity experiments suggest problem with initial conditions (ORAS5). ORAS5 before 2000 has error balance: too high northward ocean heat transport and high artificial heat extracting through relaxation to observed SST.
– Stratospheric mean temperature and wind profiles degraded.
News from C3S : ERA5

Climate Change Service

Hans Hersbach, ECMWF, and many, many colleagues
| What is new in ERA5? |
|----------------------|------------------|------------------|
| **Streams**          | 1979-1989, 1989-present | Parallel streams, one per decade |
| **Assimilation system** | 2006, 4D-Var | 2016 ECMWF model cycle (41r2), 4D-Var |
| **Model input**      | As in operations, *(inconsistent sea surface temperature)* | **Appropriate for climate**, e.g., evolution greenhouse gases, volcanic eruptions, sea surface temperature and sea ice |
| **Spatial resolution** | 79 km globally, 60 levels to 10 Pa | **31 km globally**, 137 levels to 1 Pa |
| **Uncertainty estimate** | | Based on a 10-member 4D-Var ensemble at 62 km |
| **Land Component**   | 79km | ERA5L, 9km (separate, forced by ERA5) |
| **Output frequency** | 6-hourly Analysis fields | **Hourly** (three-hourly for the ensemble), Extended list of parameters ~ 5 Peta Byte (1979-NRT) |
| **Extra Observations** | Mostly ERA-40, GTS | Various reprocessed CDRs, latest instruments |
| Variational Bias correction | Satellite radiances | Also ozone, aircraft, surface pressure |
Newly reprocessed data sets
Radiances: SSM/I brightness temp from CM-SAF METEOSAT from EUMETSAT
Atmospheric motion vector winds: METEOSAT, GMS/GOES-9/MTSAT, GOES-8 to 15, AVHRR METOP and NOAA
Scatterometers: ASCAT-A, ERS 1/2 soil moisture
Radio Occultation: METOP GRAS, COSMIC, CHAMP, GRACE, SAC-C, TERRASAR-x
Ozone: NIMBUS-7, EP TOMS, ERS-2 GOME, ENVISAT SCIAMACHY, Aura MLS, OMI
Altimeter: ERS1/2, ENVISAT, Jason-1
Extra data (not used in ERA-Interim)
lack of infrastructure ERA-Interim
IASI, ASCAT, ATMS, Cris, MWHS2, Himawari-8 …

Typically the latest instruments:
ERA5 is more future proof!

Improved data usage
all-sky vs clear-sky assimilation, latest radiative transfer function,
ERA5 provides an estimate for uncertainty Spread in Surface Pressure (hPa)

ERA5 is based on a 10-member EDA system

January 1979

Spread in Surface Pressure (hPa)

July 2014
Hourly reanalysis fields

ERAS 2-metre temperature compared to independent data

Observation feedback archive
Comparison with other long data sets

12-month running mean precipitation over Europe (mm/day)

12-month running mean precipitation over Africa (mm/day)
• ERA5 much better than ERA-Interim,
• but not as good as ECMWF operations
Update on ERA5

ERA-Interim is 10 years old and needs replacement

The production of ERA5 is well underway:
- Higher resolution, hourly output, uncertainty estimate.
- Produced in parallel streams
- Public Release 2010-2016 end July 2017
- Release other stream to be done in stages within CDS

The performance of ERA5 is very promising in the troposphere.
- Improved global hydrological and mass balance
- Reduced biases in precipitation,
- Refinement of the variability and trends of surface air temperature.
- …

There are some imperfections, though
- Bias upper stratosphere
- Tropical jet mesosphere
- Initially there were quality issues over the southern hemisphere in the 1980s (delay in production stream)

At ECMWF activities are focused towards a coupled Earth system
- Benefit to reanalysis (ERA6)
Sea ice cover – bias against ERA-Interim

…at the expense of the introduction of sea ice biases.
ERA5 Release Plan

Access: initially similar to ERA-Interim (Web-API)
later (Jan 2018) via the C3S Climate Data Store

Q3/4 2017: 2017 – timely updates
• ERA5: Updates with about 2-months delay (final product)
• ERA5T: Updates with short delay (<1 week, preliminary product)

Q1/2 2018: Release 1979 – 2009:
• Continue ERA5 timely updates
• Continue ERA-Interim for another 6 months

2018: integration of ERA5 segment from 1950
SEAS5 loss of DJF surface temperature skill over part of North Atlantic:
due to warm SST bias in early period that disappears around 2000
sensitivity experiments suggest problem with initial conditions (ORAS5)
ORAS5 before 2000 has error balance: too high northward ocean heat transport and high artificial heat extracting through relaxation to observed SST
1) Changing observing system
Quality of ocean initial conditions not constant in time

2) Decadal Signals and Regime shifts:
Non stationary climate may lead to non stationary errors.

SST anomalies in Nwest Atlantic

Mixed Layer depth in Nwest Atlantic
The improved mean state winds improve the forecasts of the QBO to be comparable with, or better than, SEAS4.

Decreasing GGAUSSB also improves DJF 60N U10 forecasts. Polar vortex forecasts improved from 1-100 hPa.
To improve the winds biases in SEAS5, non-orographic gravity wave drag in the tropics is reduced by decreasing GGAUSSB from -0.25 to -0.95. This is being considered for inclusion in a future IFS cycle.

Decreasing GGAUSSB significantly improves the zonal winds in the stratosphere, but has only a small impact on the temperature.