Task Team for the Intercomparison of ReAnalyses (TIRA)

Michael Bosilovich
(drawing on input from the TIRA telecons)
Main Objectives of TIRA

- The primary charge to the TIRA is to develop a reanalysis intercomparison project plan that will attain the following objectives.
  1) To foster understanding and estimation of uncertainties in reanalysis data by intercomparison and other means
  2) To communicate new developments and best practices among the reanalyses producing centers
  3) To enhance the understanding of data and assimilation issues and their impact on uncertainties, leading to improved reanalyses for climate assessment
  4) To communicate the strengths and weaknesses of reanalyses, their fitness for purpose, and best practices in the use of reanalysis datasets by the scientific community
Task Team Members

- Magdelena Balmaseda (ECMWF/CLIVAR)
- Michael Bosilovich (NASA/GMAO/USA Co-Chair*)
- Cathy Smith (CIRES/WRIT/USA)
- Gil Compo (CIRES/20CR/USA)
- Chris Derksen (ECCC/CliC/Canada)
- Masatomo Fujiwara * Co-Chair (JMA/SPARC/Japan/S-RIP)
- Jan Keller * Co-Chair (DWD/Regional Reanalysis)
- Hans Hersbach (ECMWF)
- Shinya Kobayashi (JMA)
- Wesley Ebisuzaki (NOAA/EMC/USA)
- Remy Roca (GEWEX)
- Chenghu Sun (CMA/NMIC)
- Andrea Storto (CCMC)
- Gerald Potter (NASA/CREATE/USA)
- Otis Brown (NCSU/USA/WDAC)
- Matthias Tuma (WCRP)

*New Co-Chair
Telecons

- Recent Telecon Topics/Highlights
  - CREATE-IP status and future additions and developments (e.g. an ensemble of reanalyses)
  - Discussions on usefulness of older reanalyses, should they be retired, or limited
  - Develop a pilot intercomparion project, something to start fueling real work and contributions
  - Collecting a listing of existing Intercomparison work: [https://goo.gl/forms/0jwcuPwo8HIdwnqo2](https://goo.gl/forms/0jwcuPwo8HIdwnqo2)
TIRA Overview at WCRP 5th International Conference on Reanalyses

- Presented the motivation and current activities at ICR5 (Rome, Nov 2017)
Pilot Intercomparison

• At ICR5 – group discussion on next steps needed to define a WCRP Project for the Intercomparison of Reanalyses
• Document – develop a document that highlights best practices and terms of reference
• Somewhat more interest: Develop one (or more) Pilot Intercomparison Project(s) that some in the team can start, with a goal of real world experience interacting in group activities that have some direct affect on TIRA and the participants

• Regional Project - Precipitation
• Possible Global Topics
• [1] Surface temperature
• [2] Ocean surface fluxes
• [3] Precipitation
• [4] Radiation
• [5] Energy budget
• [6] Water cycle
• [7] Surface Winds (Wind Energy)
• Other ideas for global atmospheric reanalyses?
Pilot Energy Budget IP

Top of Atmosphere Absorbed Solar Radiation

- NERC- Allan DEEP-C extension of CERES intercalibrated data into the past
- CFSR (or “CDAS-T382”) can be extended to the end of December 2010 – and can be further continued using CFSv2 (or “CDAS-T574”).
- MERRA-2 and M2AMIP have a too strong response to Mt. Pinatubo eruption, and MERRA-2 clouds increase over time, reflecting more SW.

- Can we specify the reason for the bias of each reanalysis? Ask inputs from each reanalysis center?
- It looks the signals of El Chichon eruption (April 1982) and Mount Pinatubo eruption (June 1991) can be clearly seen in the reanalyses that have volcanic aerosols (i.e., MERRA-2, CFSR, ERA-20C (and 20CR)). ASR is negative because scattering to the space was enhanced.
Pilot Energy Budget IP

Global Monthly (12mo) Sfc LW↓ (W m⁻²)

Downward Longwave Radiation at the Surface

- JRA-55 has a gap around 1993/94. CFSR (or “CDAS-T382”) can be extended to the end of December 2010 – and can be further continued using CFSv2 (or “CDAS-T574”).
- MERRA, MERRA-2 and M2AMIP use Chou Suarez radiation parameterization. This underestimates cloud effects, so the LW down is biased low. This is being addressed for future reanalyses.
- GEWEX Surface Radiation Budget - a new version is coming “soon”

- This is largely determined by the atmospheric temperature (i.e., ENSO related), plus by the increasing CO2 level?
- Can we specify the reason for the bias of each reanalysis? (All are too low (compared to “SRB”)?) Ask inputs from each reanalysis center?
Joint Activities

- **Concept:** Common issues can be present in more than one reanalysis, or new methods make help produce improved analysis.
- **Action:** Determine which centers can participate. Develop an experimental plan including case studies and/or additional diagnostic output.
- **Cost:** Developing centers incur computing and time to evaluate the experiments.
- **Benefit:** Should provide more understanding of the reanalysis method than could be accomplished alone.
Developing a Reanalysis Intercomparison Project

• Perhaps more of a coordinating body, than an actual project
• Could have membership that includes the disciplinary projects as well as developing centers
• Maintain and promote best practices and promotes communication of results
• Still needs discussion
Examples of S-RIP Studies

1. Tropical Stratospheric Puzzle: Quasi-Biennial Oscillation (QBO)
2. Ozone Depletion and Stratospheric Meteorology
3. Upper Troposphere – Lower Stratosphere (UTLS): Jets and their role in Climate
4. Volcanic Eruption and Climate

[Fujiwara et al., ACP, 2017]

Inter-journal special issue on "The SPARC Reanalysis Intercomparison Project (S-RIP)" in Atmospheric Chemistry and Physics (ACP) and Earth System Science Data (ESSD) - 19 papers
Ocean Re-Analyses: Demonstrating the value of ocean observations

ORA-IP: Ocean Reanalysis Intercomparison Project

Objectives:

To quantify signal/noise from Ensemble
To gain insight into ocean variability and trends
To identify current system deficiencies
To measure progress
To exploit existing multi-ORA ensemble
  For real-time ocean monitoring
  For climate indicators
  For model validation
  For initialization of coupled models
Upcoming New **WRIT** (Web-based Reanalysis Intercomparison Tools) from NOAA ESRL/PSD

WRIT seasonal correlations (new)

*AO correlation with R1 March T at 283E*

*PNA correlation with 20CRV2c Jan 500Z*

*NH Ice Extent for summer lagged correlation with spring HadISST1.1 SST*

WRIT Time-series and Climate Indices (soon)

Add functionality to WRIT time-series page:
- Add climate and ocean index time-series. For example PNA, NP, Nino 3.4.
- Calculate indices from different reanalysis datasets
- Allow lead/lag
- Add additional statistical techniques such as Wavelet analysis.

WRIT Vertical Profiles

Plot different vertical products:
- Vertical profiles/Skew-T
- Vertical transects
- Height-Time

WRIT Time-sections

Plot Daily means or anomalies
- Time/latitude or Time/longitude

*SE US Feb 19-20 1884 tornado outbreak 20CRV2c*

*US 1000mb Ta from R1 02-03/2018 (tornadoes)*
BAMS paper on reanalysis service

May 2018 issue of the *Bulletin of the American Meteorology Society*

- Describes repackaging and consistent distribution of the world’s major atmospheric and oceanic reanalyses.
- Presents examples of the usefulness of examining multiple reanalyses.
- Each reanalysis is updated as it becomes available and added to the Earth System Grid Federation (ESGF).
- Selected data is also available for subsetting (TDS), visualization (CREATE-V) and server side analytics (EDAS).
NASA NCCS’s CREATE-V provides quick look reanalysis comparison capability

• For multiple reanalyses quick look visualization and comparison.

• Includes both atmospheric and ocean reanalyses as well as ensemble means and standard deviations.

• Options to select date, level, color map, and scale.

Precipitable water for 4 reanalyses, the multiple reanalysis ensemble average and standard deviation.
Multiple Reanalysis Ensemble (MRE) and Earth Data Analytics Service (EDAS)

- NASA NCCS CREATE service produced a multiple reanalysis ensemble (MRE) of selected variables. The regridded data, the ensemble mean and the ensemble standard deviation are all published on the Earth System Grid Federation.
- EDAS is a server side analytics service that provides external users the ability to run computations such as min, max, sum, average, anomaly on the CREATE-IP reanalysis data, including the MRE, without downloading the data.

Annual averaged GPCP precipitation comparison with the MRE.

Jupyter Notebook example using remote high performance computing to analyze reanalysis data.
Atmospheric Reanalysis Plans

• Recent Contributions
  – JMA
  – NASA GMAO
  – ERA
  – NCEP
  – CMA
Having a deeper understanding of model biases and impact of changing observing systems is important for evaluating and improving temporal consistency of reanalysis.

To this end, different types of product have been produced with the common NWP system.

- **JRA-55 (JMA)**
  - Full observing system reanalysis
  - Available from JMA, DIAS, NCAR, ESGF
  - Poster by Y. Harada (Section 4 on Wed.)

- **JRA-55C (MRI/JMA)**
  - Using conventional observations only
  - Available from DIAS, NCAR
  - Poster by C. Kobayashi (Section 4 on Wed.)

- **JRA-55AMIP (MRI/JMA)**
  - AMIP-type simulation
  - Available from DIAS, NCAR

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RMS errors of 2-day forecasts of geopotential height (gpm) at 500hPa averaged over the northern hemisphere

Adapted and updated from C. Kobayashi (2014)
Japanese Reanalysis for Three Quarters of a Century (JRA-3Q)

- **Reanalysis period:** 1947 to present
- **Provisional specifications**
  - Resolution: 55 km, 60 layers (JRA-55) -> 40 km, 100 layers (JRA-3Q)
  - Incorporating many improvements from the operational NWP system
    - Overall upgrade of physical processes
    - New types of observation (ground-based GNSS, hyperspectral sounders)
  - **Improved SST:** COBE-SST2 (1-deg, up to 1985) & MGDSST (0.25 deg, from 1985 onward)
  - **Improved observations**
    - Observations newly rescued and digitised by ERA-CLIM and other projects
    - Improved satellite observations through reprocessing
    - JMA’s own tropical cyclone bogus data
- **Production schedule**
  - **Q1 2019:** start production
  - **Q1 2021:** complete production for the 1991 – 2020 normal period
  - **Q1 2022:** complete production for the whole period
Surface net energy flux (January 2016)

- JRA-55 has a bias of $-11.8\ \text{W m}^{-2}$ (Kobayashi et al. 2015).
- This bias is almost halved in JRA-3Q Exp.

<table>
<thead>
<tr>
<th></th>
<th>JRA-3Q Exp</th>
<th>JRA-55</th>
</tr>
</thead>
<tbody>
<tr>
<td>August 2015</td>
<td>-12.0</td>
<td>-16.5</td>
</tr>
<tr>
<td>January 2016</td>
<td>4.6</td>
<td>-3.6</td>
</tr>
</tbody>
</table>
# GMAO reanalyses and derivative products

<table>
<thead>
<tr>
<th>Year</th>
<th>Atmosphere</th>
<th>Ocean</th>
<th>Composition</th>
<th>Enhancements</th>
<th>Biogeochemical</th>
</tr>
</thead>
</table>

Planned
GMAO coupled atmosphere-ocean assimilation development

- **GMAO ADAS**
  - Update LSM, Convection, Radiation
  - 4D-EnVar
  - 12-km L72
  - Aerosols
  - AO Skin SST

- **MERRA-2 Ocean**
  - May 2018
  - May 2019

- **S2S v2**
  - Oct 2017
  - MOM5 0.5° L40
  - CICE
  - UMD LETKF

- **S2S v3**
  - Jan 2018
  - MOM5 0.25° L50
  - Catchment-CN
  - Salinity
  - Sea ice Thickness

- **GEOS ADAS**
  - Jan 2021
  - Update Microphysics
  - 9-km L132
  - Nonhydrostatic

- **GEOS AODAS**
  - Jan 2017
  - MOM6
  - New CICE
  - GSI O-LETKF

- **Next Reanalysis S2S Prediction NWP**
  - Jan 2021

- **Atmospheric DAS**
  - Jan 2017
  - Update Microphysics
  - 9-km L132
  - Nonhydrostatic

- **Seasonal Prediction System**
  - May 2018
  - May 2019

- **Atmosphere-Ocean Coupled DAS**
  - Jan 2017
  - Update Microphysics
  - 9-km L132
  - Nonhydrostatic

- **GEOS ADAS**
  - Jan 2021
  - Update Microphysics
  - 9-km L132
  - Nonhydrostatic

- **GEOS AODAS**
  - Jan 2017
  - MOM6
  - New CICE
  - GSI O-LETKF
HAQI shown here combines $\text{O}_3$, $\text{NO}_2$ and $\text{PM}_{2.5}$
## What is new in ERA5?

<table>
<thead>
<tr>
<th></th>
<th>ERA-Interim</th>
<th>ERA5</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Period</strong></td>
<td>1979 - present</td>
<td>Initially 1979 – present, later addition 1950-1978</td>
</tr>
<tr>
<td><strong>Start of production</strong></td>
<td>August 2006</td>
<td>2016, 1979-NRT early 2018</td>
</tr>
<tr>
<td><strong>Assimilation system</strong></td>
<td>2006, 4D-Var</td>
<td>2016 ECMWF model cycle, 4D-Var</td>
</tr>
<tr>
<td><strong>Model input</strong></td>
<td>As in operations,</td>
<td>Appropriate for climate, e.g.,</td>
</tr>
<tr>
<td></td>
<td><em>(inconsistent sea surface temperature)</em></td>
<td>evolution greenhouse gases, volcanic eruptions, sea surface temperature and sea ice</td>
</tr>
<tr>
<td><strong>Spatial resolution</strong></td>
<td>79 km globally</td>
<td>31 km globally</td>
</tr>
<tr>
<td></td>
<td>60 levels to 10 Pa</td>
<td>137 levels to 1 Pa</td>
</tr>
<tr>
<td><strong>Uncertainty estimate</strong></td>
<td>Based on a 10-member 4D-Var ensemble at 62 km</td>
<td></td>
</tr>
<tr>
<td><strong>Land Component</strong></td>
<td>79km</td>
<td>9km</td>
</tr>
<tr>
<td><strong>Output frequency</strong></td>
<td>6-hourly Analysis fields</td>
<td>Hourly (three-hourly for the ensemble),</td>
</tr>
<tr>
<td></td>
<td></td>
<td><em>Extended list of parameters ~ 5 Peta Byte</em></td>
</tr>
<tr>
<td><strong>Extra Observations</strong></td>
<td>Mostly ERA-40, GTS</td>
<td>Various <em>reprocessed CDRs, latest instruments</em></td>
</tr>
<tr>
<td><strong>Variational Bias correction</strong></td>
<td>Satellite radiances</td>
<td>Also ozone, aircraft, surface pressure</td>
</tr>
</tbody>
</table>
Historical Reanalysis Status and Plans

20th Century Reanalysis Project [http://go.usa.gov/XTd]

- **Fall 2014**: 1871-2012 (includes time-varying CO2, volcanic aerosols, GFS from NCEP). **Ensemble mean and spread and individual member variables online now.**
  - [http://www.esrl.noaa.gov/psd/data/gridded/data.20thC_ReanV2.html](http://www.esrl.noaa.gov/psd/data/gridded/data.20thC_ReanV2.html) (NOAA ESRL)
  - [http://dss.ucar.edu/datasets/ds131.1](http://dss.ucar.edu/datasets/ds131.1) (NCAR)
  - [http://portal.nersc.gov/20C_Reanalysis](http://portal.nersc.gov/20C_Reanalysis)
    - Every member (US Dept of Energy, NERSC)
  - NERSC High Performance Storage System Tape Gateway **Every member**
  - Earth System Grid Federation ana4MIPS distribution and validation for IPCC AR5
  - British Atmospheric Data Center (BADC)

**20CR v2c** [http://go.usa.gov/XTd]

*Ensemble mean and spread and 3D individual member variables online now.*

- **Spring 2016**: 1851-2012, 2013-2014 extension
  - Very similar system to 20CRv2. Fixed Sea ice using COBE-SST2 sea ice.
  - distribution via: ESRL, NCAR, NERSC **Every member**

**20CR version 3**

- **Winter 2017**: 1851-2015, additional tests for 1815-1850

Higher resolution, improved algorithm and observational quality control
Coordinate with ERA-CLIM2, SOUSEI, GFDL - Test possible BCs: HadISST2.1, COBE-SST2, SODAsi.3
Goal of CMA 40-year Global Reanalysis (CRA-40)

Produce 40-year datasets (1979-2018):
- Ingested observations
- Reanalysis datasets: CMA Reanalysis (~30km, 6 hourly)
- Obs. feedback datasets: departure from analysis & 6h forecast
- Reanalysis uncertainty: from EnKF ensembles

Will become an operational system: CMA Re-Analysis System — CRAS
- Continuously running in near real time for climate monitoring
Summary

• Reanalysis Data Development is still going strong - Earth System coupling plans are moving forward
  – More important than ever for users to understand the reanalysis methodology and foundations

• Tools and data access are growing and improving
  – Users still need guidance on strengths and weaknesses

• TIRA pilot projects are moving forward and will contribute to a plan for the structure of a general intercomparison project for reanalyses
Example: Clausius-Clapyeron

- Using TLT and TPW, MERRA-2 shows a weaker C-C relationship compared to RSS obs and AMIP simulation.
- Analysis increment counters some local evaporative increases.
- Other reanalyses also show a weak C-C relationship.
- Bosilovich et al. (2016, J Clim); Schröder et al. (2016, JAMC)
Ocean Anomalies: TPW, Evaporation and Analysis Increment

- TPW does respond to SST (e.g. apparent ENSO signal)
- E-P is increasing over the period, generally in response to SST, but also varies according to wind.
- Increment is always negative, and decreases in time – countering a model wet bias.
- In MERRA-2, it appears the Analysis is damping C-C.
Extension to Other Systems using T850 as a Proxy

<table>
<thead>
<tr>
<th>System</th>
<th>T</th>
<th>Q</th>
<th>dT/dt</th>
<th>dQ/dt</th>
<th>%/K Detrend</th>
<th>%/K Trend</th>
<th>%/K S(Q)/S(T)</th>
<th>Corr(T,Q)</th>
</tr>
</thead>
<tbody>
<tr>
<td>OBS</td>
<td>TLT</td>
<td>TPW</td>
<td>0.10</td>
<td>1.03</td>
<td>4.6</td>
<td>5.4</td>
<td>6.2</td>
<td>0.90</td>
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<tr>
<td>MERRA2</td>
<td>TLT</td>
<td>TPW</td>
<td>0.11</td>
<td>0.15</td>
<td>3.2</td>
<td>2.9</td>
<td>3.7</td>
<td>0.78</td>
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<tr>
<td>M2AMIP</td>
<td>TLT</td>
<td>TPW</td>
<td>0.28</td>
<td>1.53</td>
<td>4.5</td>
<td>5.0</td>
<td>7.1</td>
<td>0.97</td>
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<tr>
<td>MERRA2</td>
<td>T850</td>
<td>TPW</td>
<td>0.20</td>
<td>0.15</td>
<td>4.0</td>
<td>2.3</td>
<td>5.3</td>
<td>0.63</td>
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<td>TPW</td>
<td>0.24</td>
<td>1.53</td>
<td>6.0</td>
<td>6.2</td>
<td>3.7</td>
<td>0.97</td>
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<tr>
<td>ERAI</td>
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<td>TPW</td>
<td>0.05</td>
<td>0.23</td>
<td>4.3</td>
<td>4.3</td>
<td>10.9</td>
<td>0.58</td>
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<tr>
<td>JRA55</td>
<td>T850</td>
<td>TPW</td>
<td>0.12</td>
<td>0.30</td>
<td>4.7</td>
<td>4.0</td>
<td>6.4</td>
<td>0.71</td>
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<tr>
<td>20CR</td>
<td>T850</td>
<td>TPW</td>
<td>0.13</td>
<td>0.84</td>
<td>6.8</td>
<td>6.7</td>
<td>6.4</td>
<td>0.95</td>
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<td>ERA20C</td>
<td>T850</td>
<td>TPW</td>
<td>0.27</td>
<td>1.42</td>
<td>7.1</td>
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<td>7.2</td>
<td>0.94</td>
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<td>0.22</td>
<td>1.38</td>
<td>7.0</td>
<td>6.5</td>
<td>5.7</td>
<td>0.98</td>
</tr>
</tbody>
</table>

- Trends are K/dec and %/decade; MERRA and CFSR withheld
Next Steps

• Need further variables to test reanalyses (TLT, ANA) more completely
  – If not a result of analysis increment in other reanalyses, then what holds back the C-C relationship?

• Test satellite reanalyses removing water vapor assimilation (likely too expensive for most or all centers to consider)