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

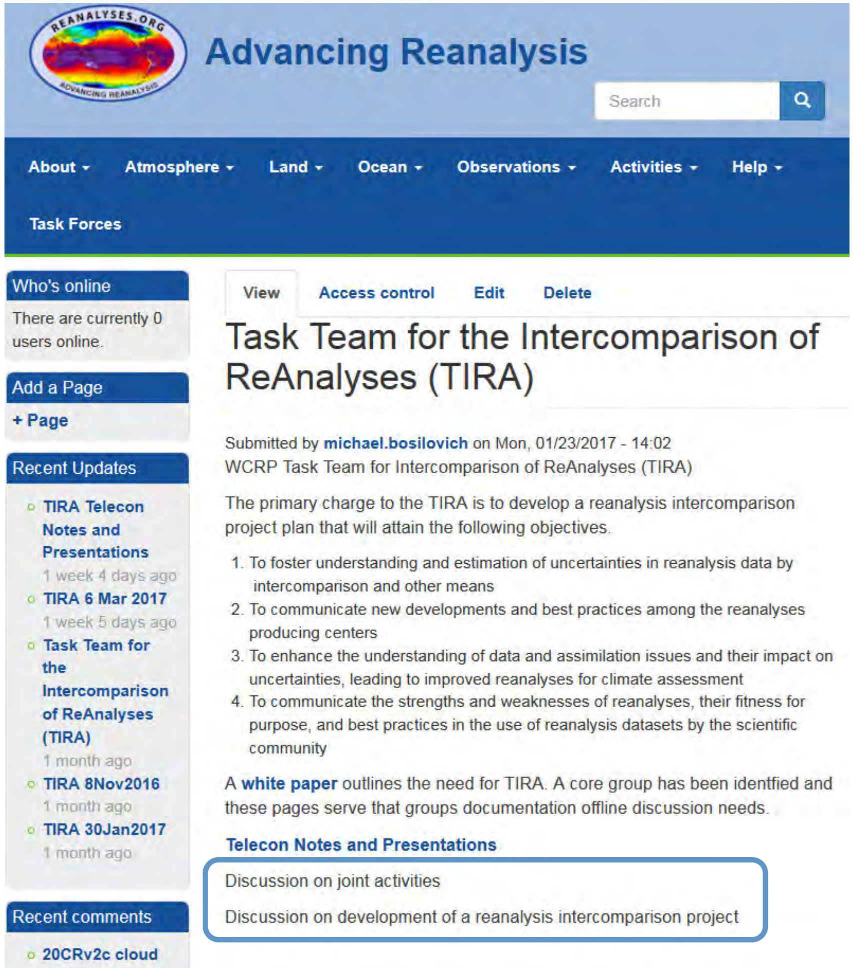
Task Team Members

- 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)
- Matthais 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 Intercmparison work: 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)

WCRP Task team for the Intercomparison of ReAnalyses (TIRA): Motivation and Progress
Presented by Michael Bosilovich

Motivation

The primary charge to TIRA is to develop a reanalysis intercomparison project plan to 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

Current Membership

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Significant Departures in Reanalyses

The differences among reanalyses and their inherent uncertainties are some of the most important questions for both users and developers of reanalyses. Therefore, a collaborative effort to systematically assess and intercompare reanalyses would be a logical progression that fills the needs of the community and contributes to the WCRP mission. Several efforts have self started to address these issues (S-RIP and ORA-IP)

While much the same sets of observations are available to all current reanalysis systems (though some methodologies call for limited observing systems), variations can occur in the actual usage of data due to the assimilation method, the way observations are selected, handled and quality controlled, and biases in various properties of the assimilating model.

Developing Tools and Communities

Performing intercomparisons requires easily accessible data. WRIT and CREATE projects are developing utilities to help users. (Above)

The SPARC community needed some understanding of the differences among reanalyses, and so, took on a reanalysis intercomparison project. SRIP provides an initial template and ideas for organizing reanalyses intercomparison. In particular, key aspects of the project have assigned names working on specific topics. In addition, CORE CLIMAX (under Copernicus climate services) has developed a technical volume on various levels of quantitative complexity of reanalysis intercomparison.

Potential Development of Common Experiments

- Concept: Common issues can be present in multiple reanalyses, need internal knowledge to understand each
- Action: Determine which centers can participate. Develop an experimental plan including case studies and/or additional diagnostic output and metrics
- Cost: Developing centers incur computing and personnel time to evaluate the experiments
- Benefit: Should provide more understanding of the reanalysis method than could be accomplished alone

Developing a Reanalysis Intercomparison Project

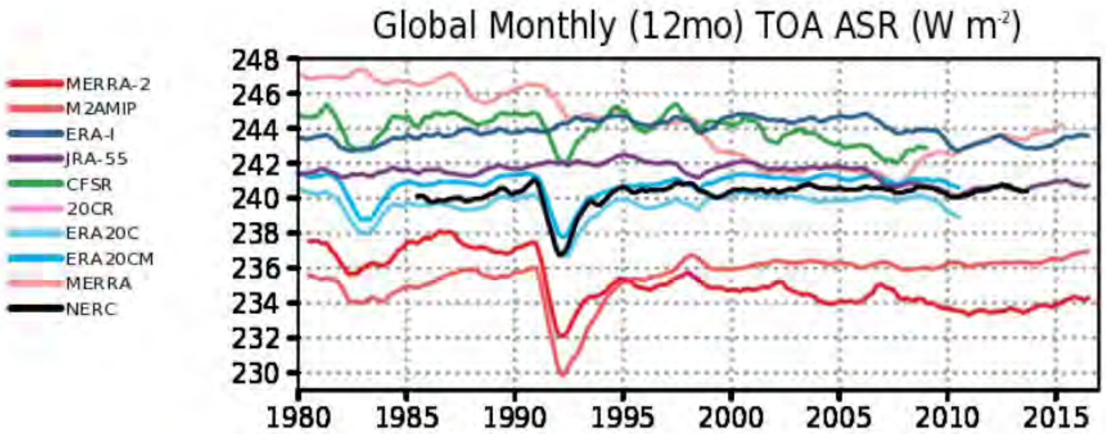
- More of a coordinating body, than an actual project
- Should have membership that includes the disciplinary projects as well as developing centers
- Maintain and promote best practices and promotes communication of results
- Development of metrics
- Formulating common experiments is possible
- Still needs discussion/input/suggestions

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

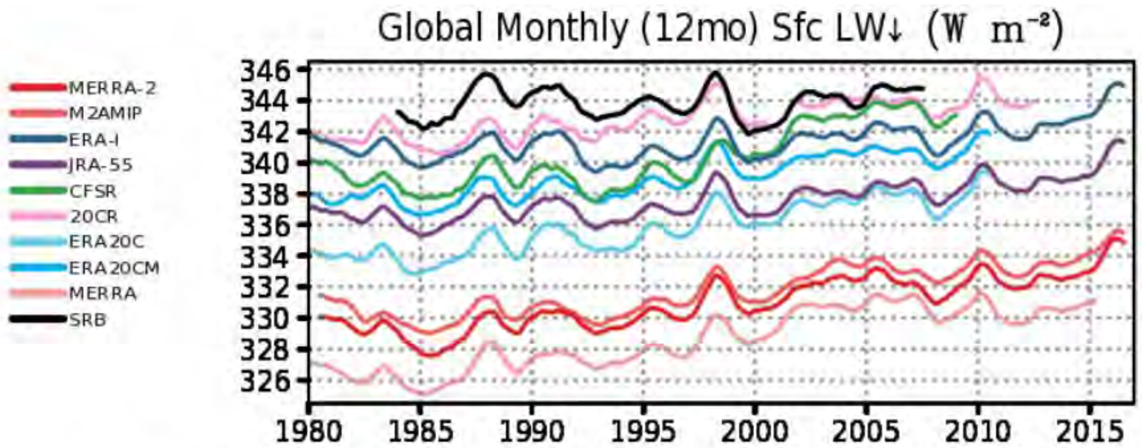


Top of Atmosphere Absorbed Solar Radiation

- 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



<u>Downward Longwave Radiation at the Surface</u>

- 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

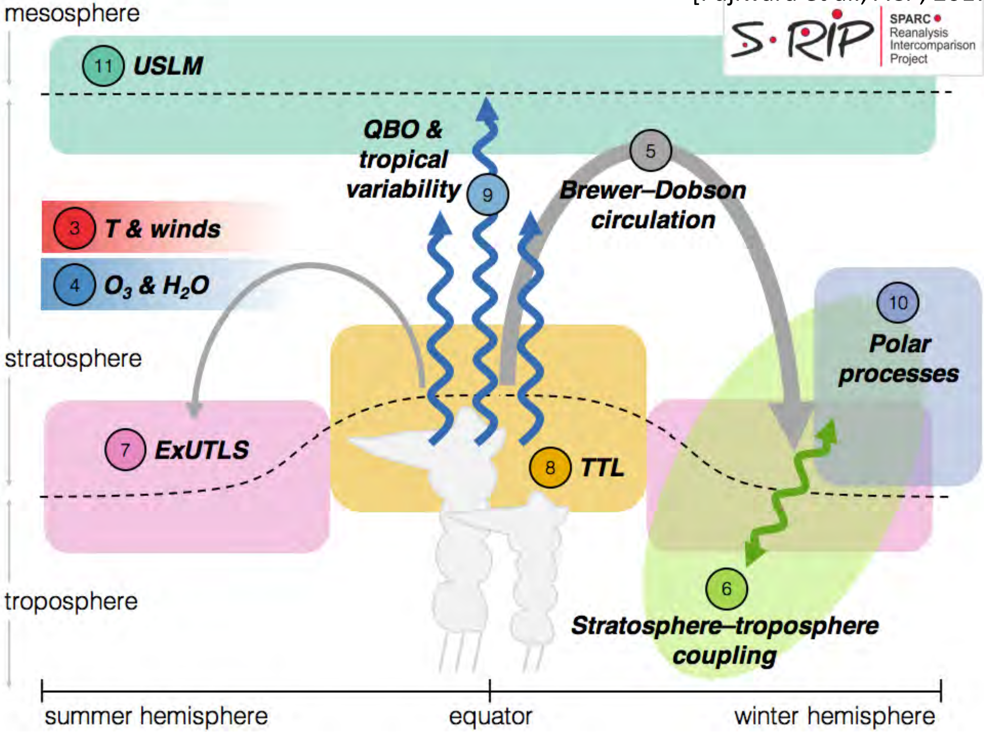
Developing a Reanalysis Intercomparison Project

- 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

ORAIP Special Issue in Climate Dynamics

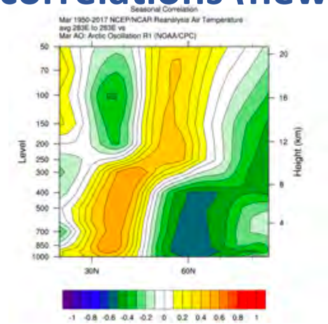
ORAIP v1 data repository with version control

Real time Multi-ORA Monitoring

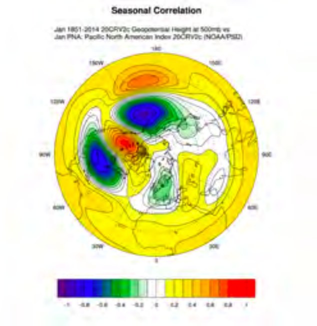
Create-IP
Concept-heat
EOS-Polar Intercomparison
CMEMS

Upcoming New **WRIT** (Web-based Reanalysis Intercomparison Tools) from NOAA ESRL/PSD

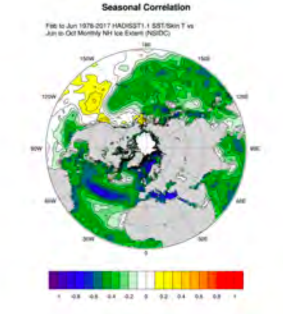
WRIT seasonal correlations (new)



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:

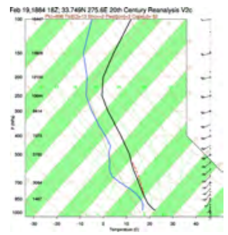
- Add climate and ocean index time-series. For example PNA, NP, Nino 3.4.
- Calculate indices from different reanalysis datasets
- Allow lead/lag
- Add additional statistical techniques such as Wavelet analysis.

WRIT Vertical Profiles

Plot different vertical products:

- Vertical profiles/ Skew-T
- Vertical transects
- Height-Time

SE US Feb 19-20 1884 tornado outbreak 20CRV2c

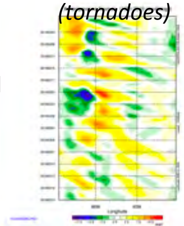


WRIT Time-sections

Plot Daily means or anomalies

- Time/latitude o Time/longitude

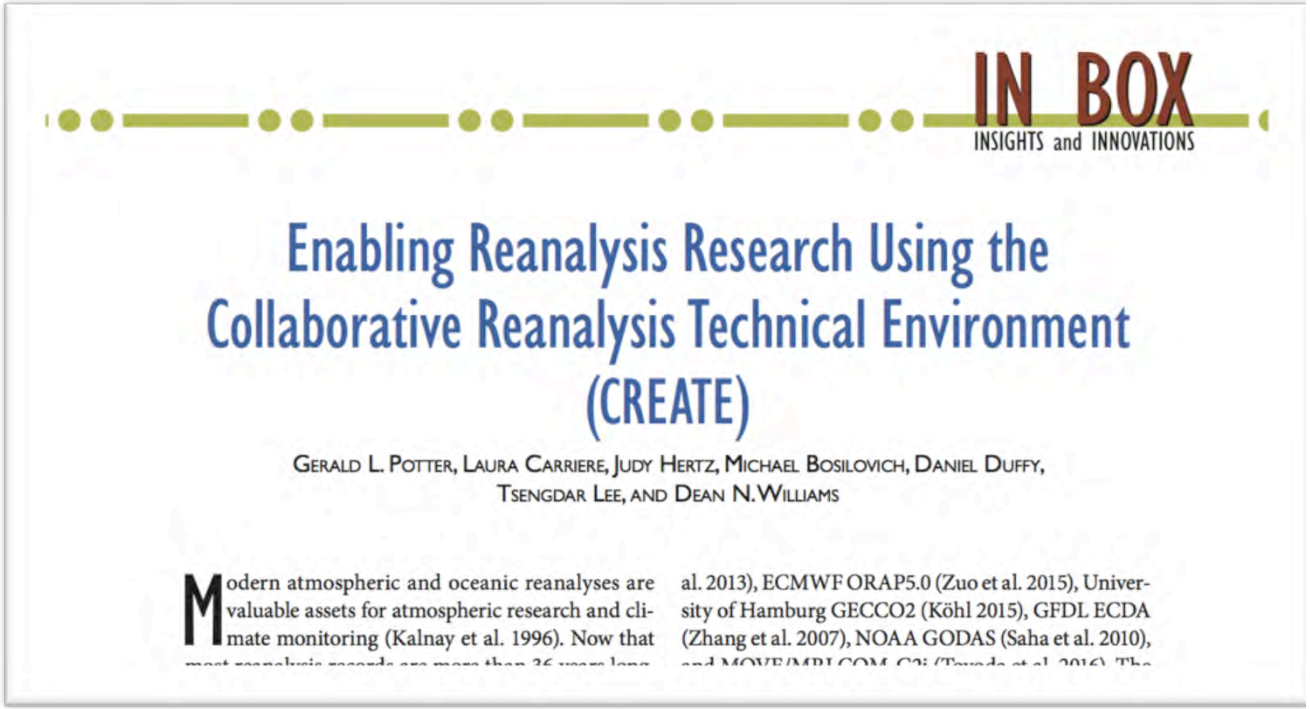
US 1000mb Ta from R1 02-03/2018 (tornadoes)



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).


IN BOX
INSIGHTS and INNOVATIONS

Enabling Reanalysis Research Using the Collaborative Reanalysis Technical Environment (CREATE)

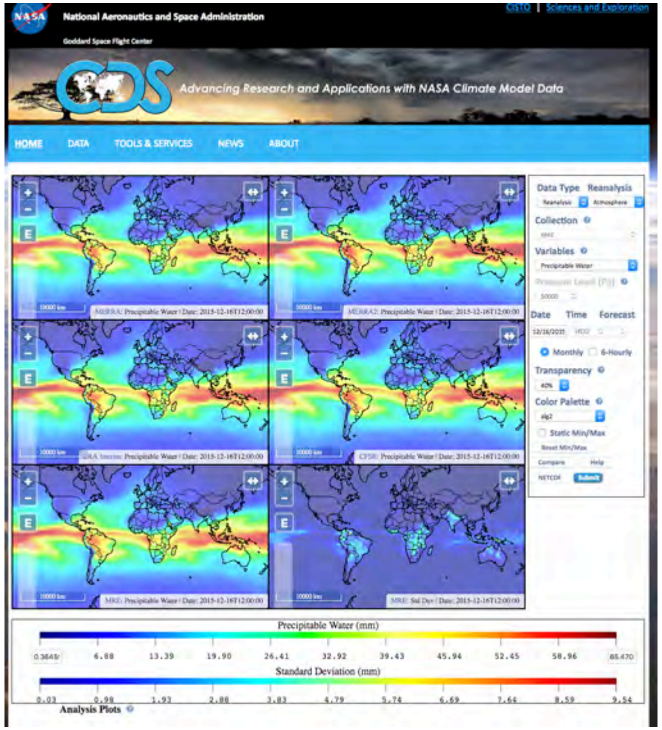
Gerald L. Potter, Laura Carriere, Judy Hertz, Michael Bosilovich, Daniel Duffy, Tsengdar Lee, and Dean N. Williams

Modern atmospheric and oceanic reanalyses are valuable assets for atmospheric research and climate monitoring (Kalnay et al. 1996). Now that

al. 2013), ECMWF ORAP5.0 (Zuo et al. 2015), University of Hamburg GECCO2 (Köhl 2015), GFDL ECDA (Zhang et al. 2007), NOAA GODAS (Saha et al. 2010),

NASA NCCS's CREATE-V provides quick look reanalysis comparison capability

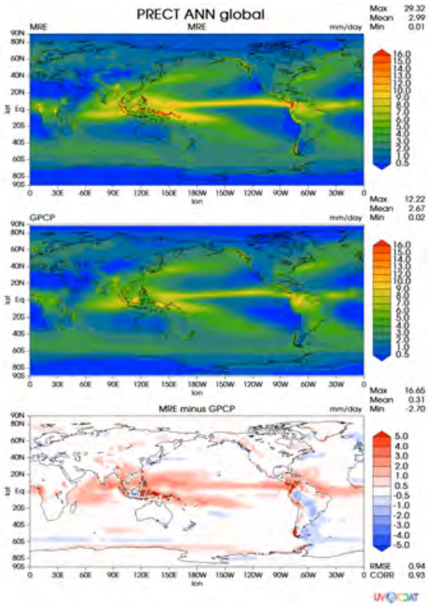
- For multiple reanalyses quick look visualization and comparison.
- Includes both atmospheric and ocean reanalyses as well as ensemble means and standard deviations.
- Options to select date, level, color map, and scale.



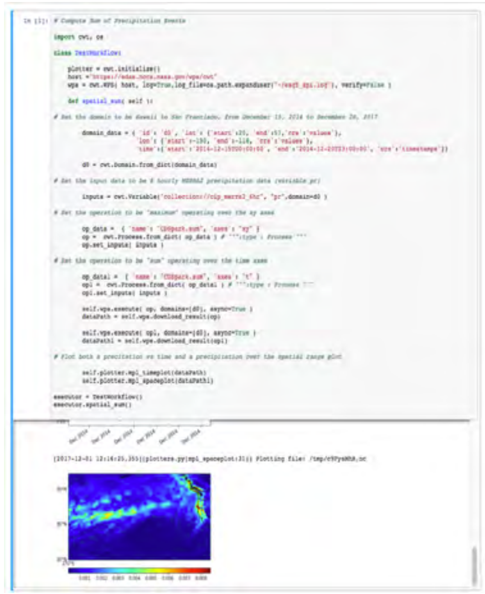
Precipitable water for 4 reanalyses, the multiple reanalysis ensemble average and standard deviation.

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.



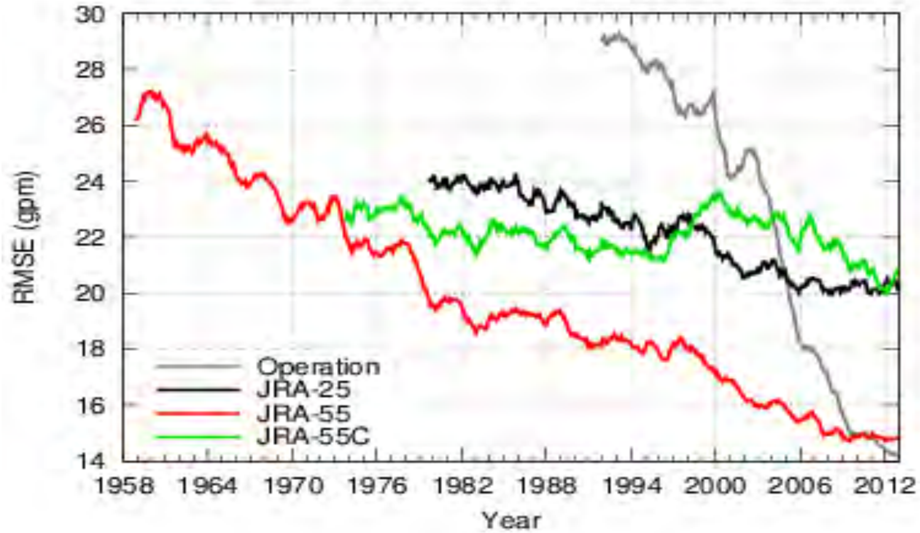
Jupyter Notebook example using remote high performance computing to analyze reanalysis data.

Atmospheric Reanalysis Plans

- Recent Contributions
  - JMA
  - NASA GMAO
  - ERA
  - NCEP
  - CMA

JRA-55 family

- 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



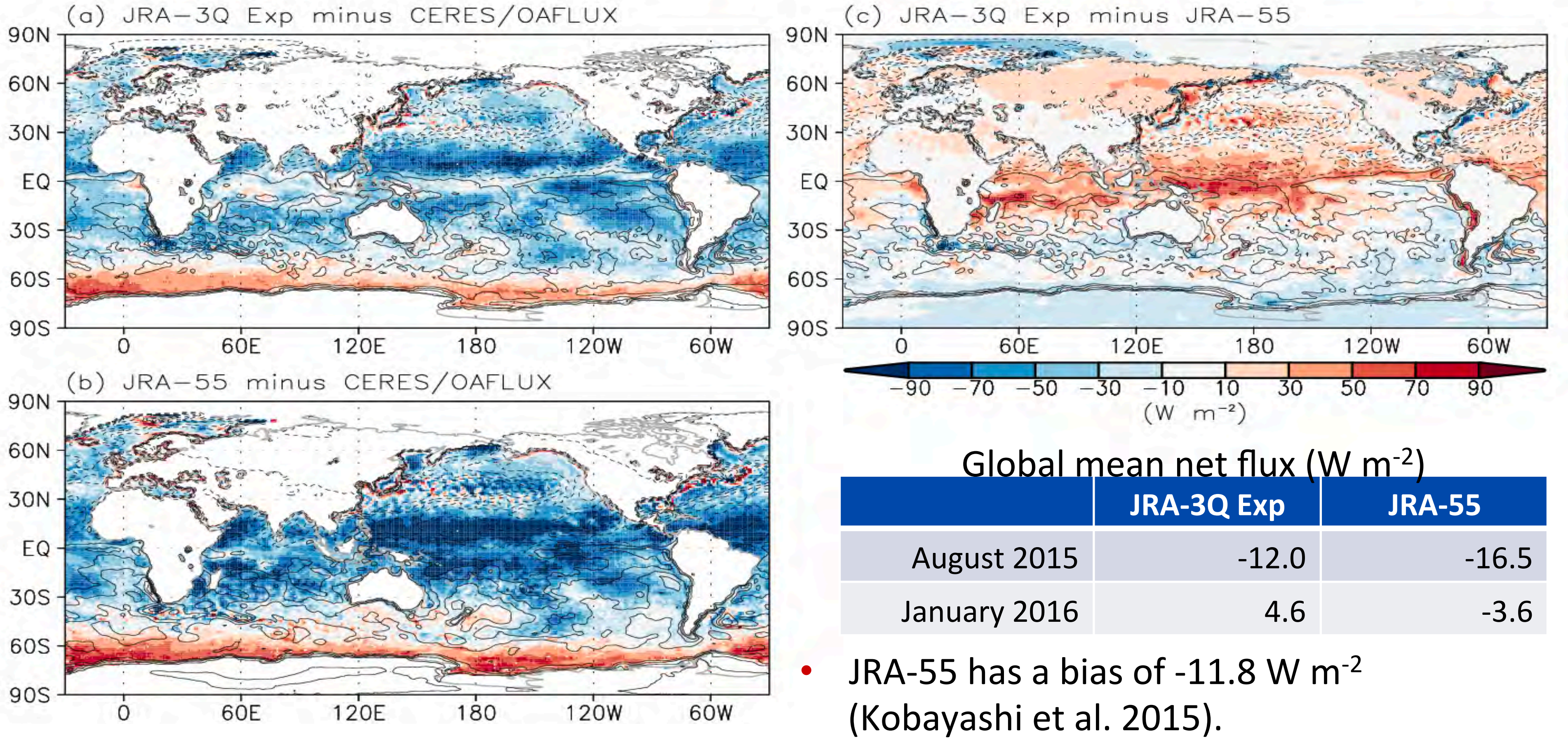
RMS errors of 2-day forecasts of geopotential height (gpm) at 500hPa averaged over the northern hemisphere

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)

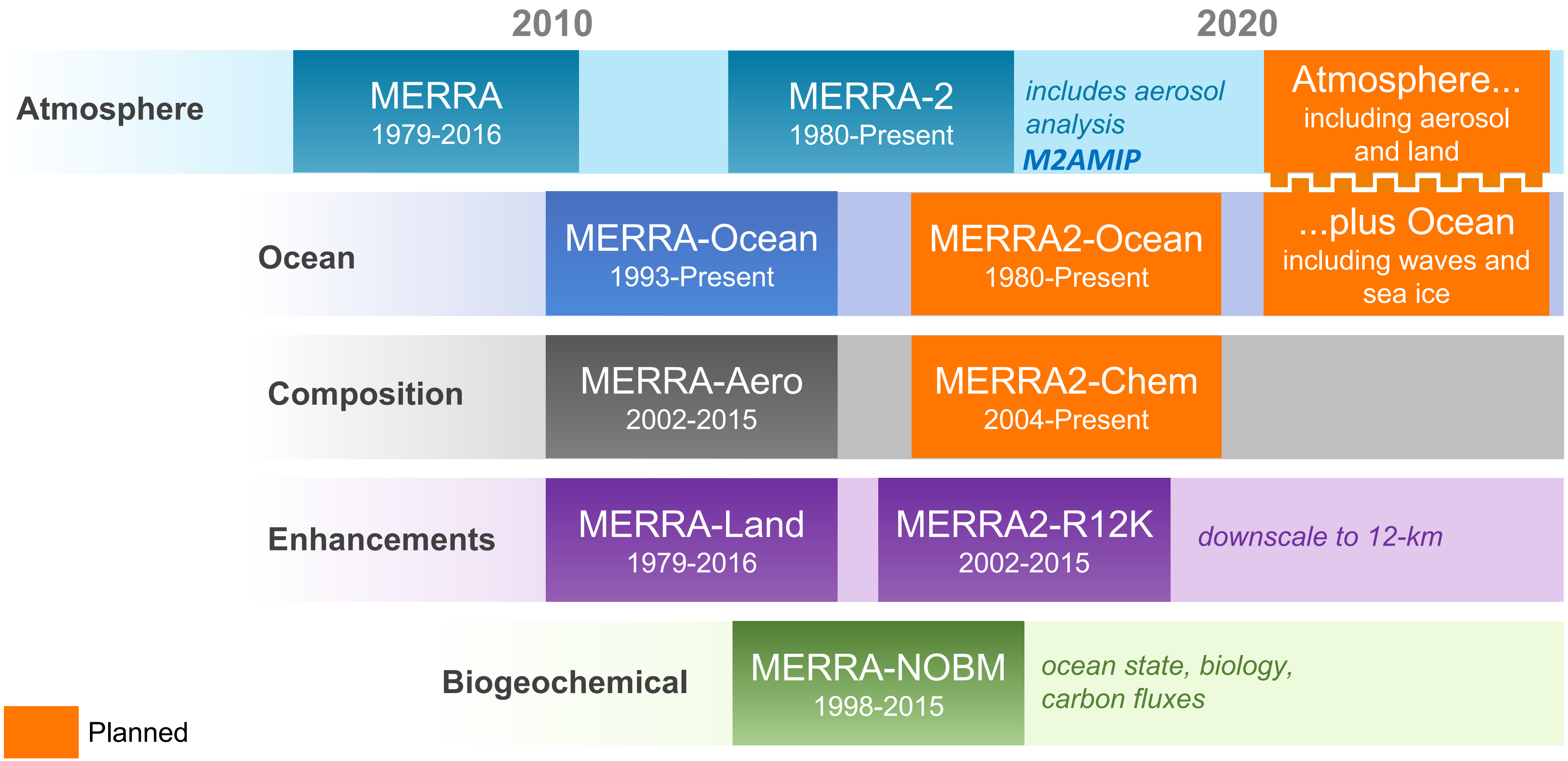


Global mean net flux (W m^{-2})

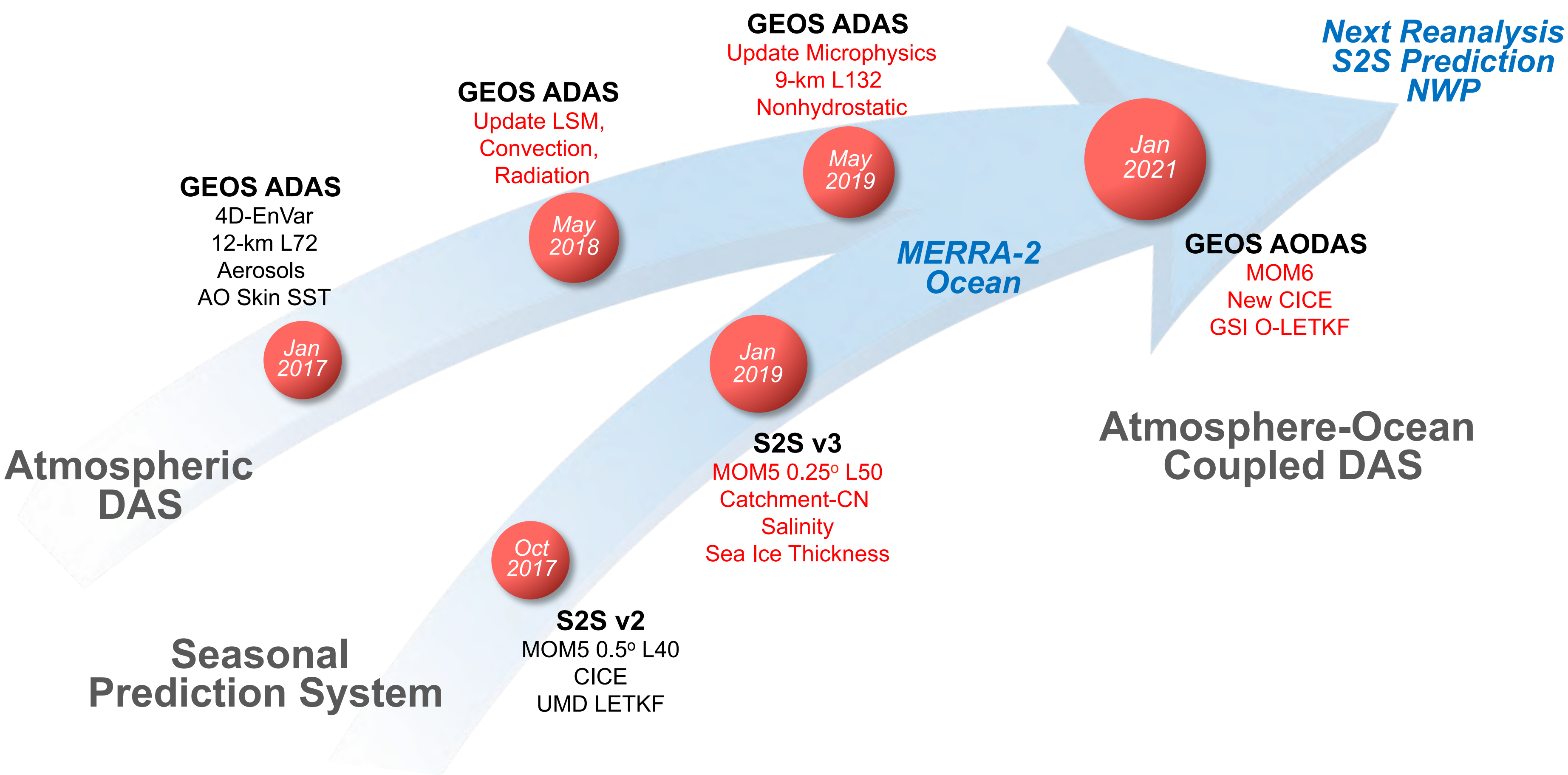
	JRA-3Q Exp	JRA-55
August 2015	-12.0	-16.5
January 2016	4.6	-3.6

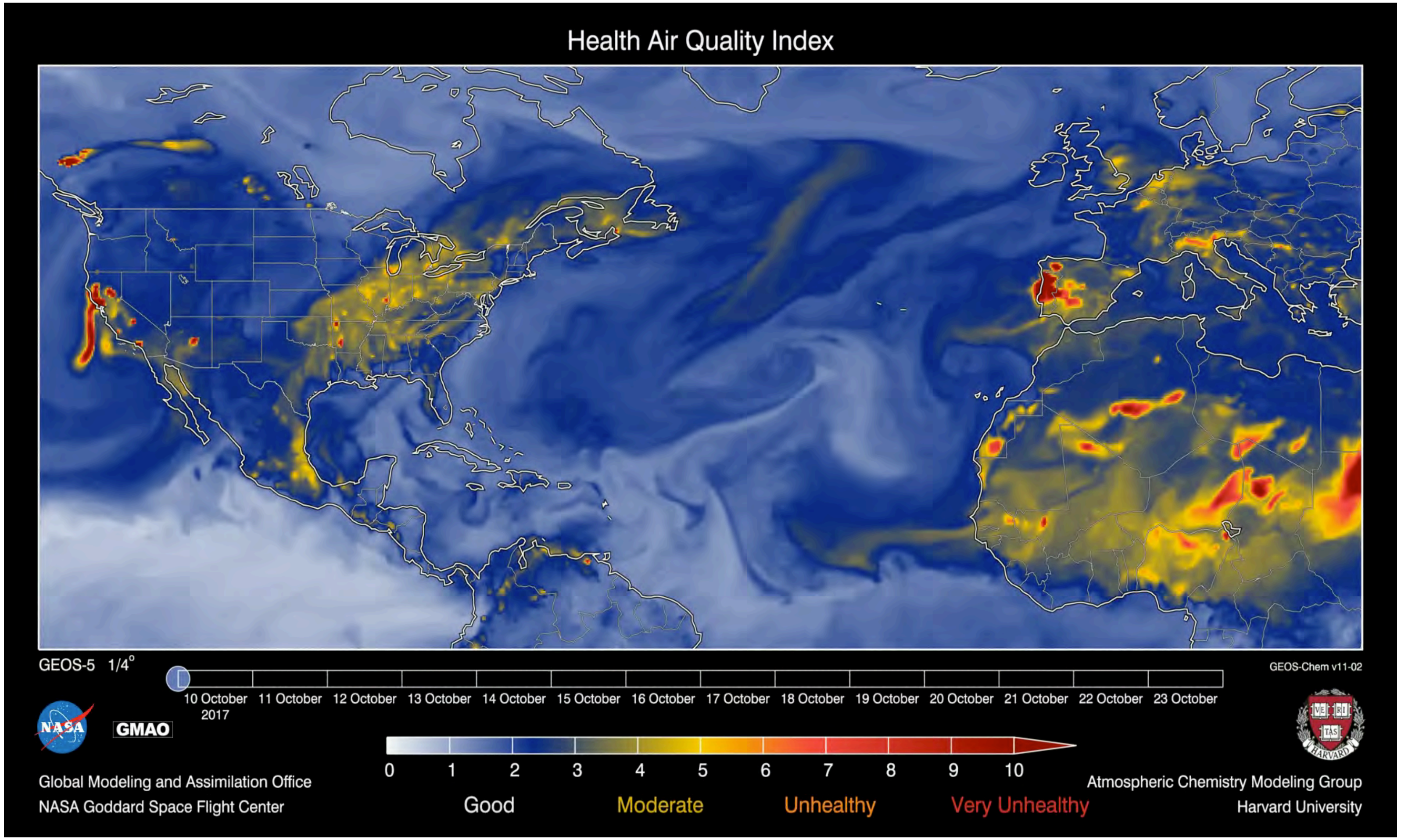
- JRA-55 has a bias of -11.8 W m^{-2} (Kobayashi et al. 2015).
- This bias is almost halved in JRA-3Q Exp.

GMAO reanalyses and derivative products



GMAO coupled atmosphere-ocean assimilation development





HAQI shown here combines O_3, NO_2 and $PM_{2.5}$

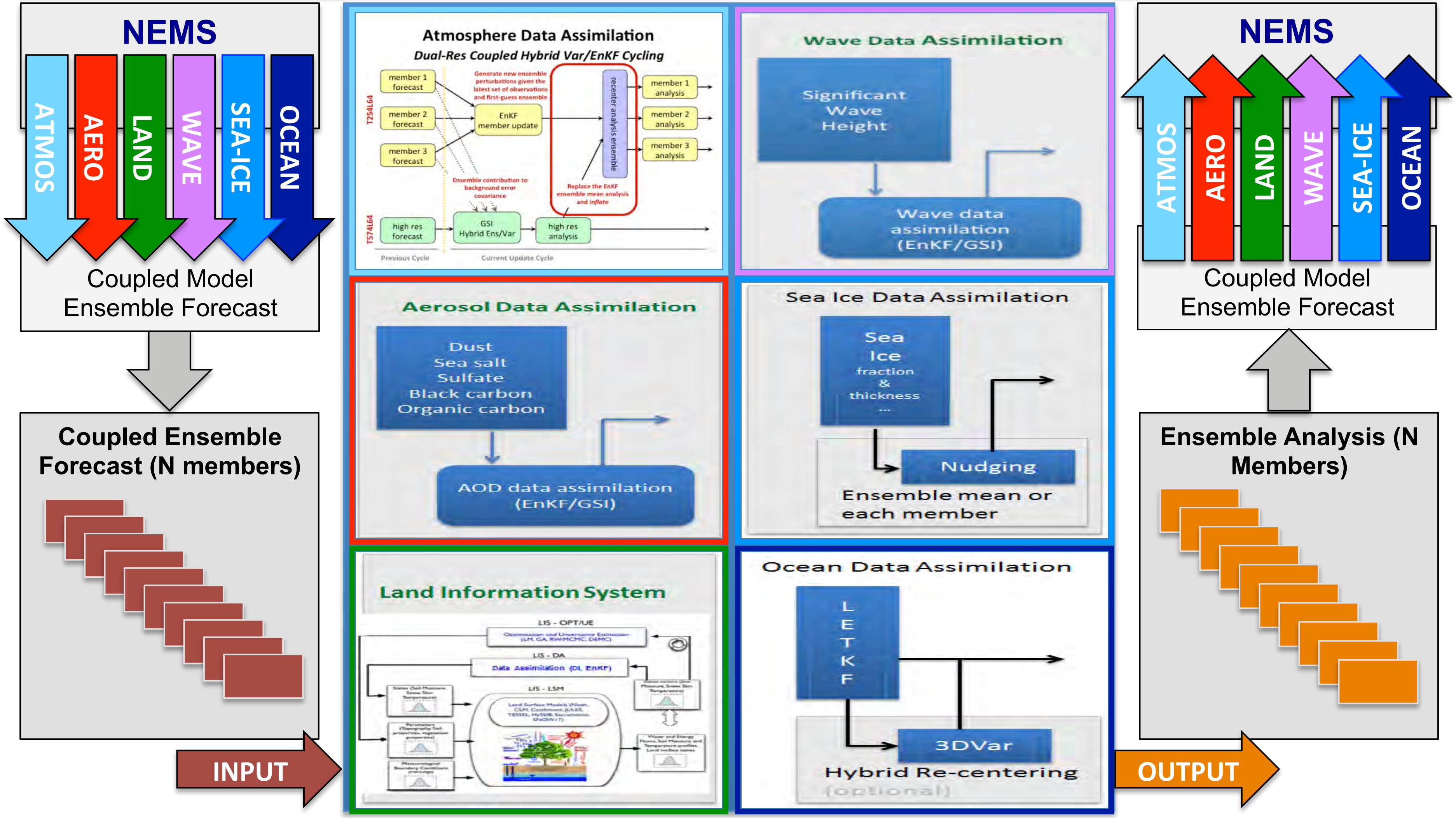
What is new in ERA5?

European Commission

	ERA-Interim	ERA5
Period	1979 - present	Initially 1979 – present, later addition 1950-1978
Start of production	August 2006	2016, 1979-NRT early 2018
Assimilation system	2006, 4D-Var	2016 ECMWF model cycle, 4D-Var
Model input (radiation and surface)	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	9km
Output frequency	6-hourly Analysis fields	***Hourly*** (three-hourly for the ensemble), ***Extended list of parameters ~ 5 Peta Byte***
Extra Observations	Mostly ERA-40, GTS	Various ***reprocessed CDRs***, ***latest instruments***
Variational Bias correction	Satellite radiances	Also ozone, aircraft, surface pressure

NCEP Coupled Hybrid Data Assimilation and Forecast System

Saha et al.



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 (NOAA ESRL)
  - http://dss.ucar.edu/datasets/ds131.1 (NCAR)
  - 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.
More observations, ensemble of SODAsi.2 SST (1851-2012), Reynolds et al. SST (2013-2014).
- 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)

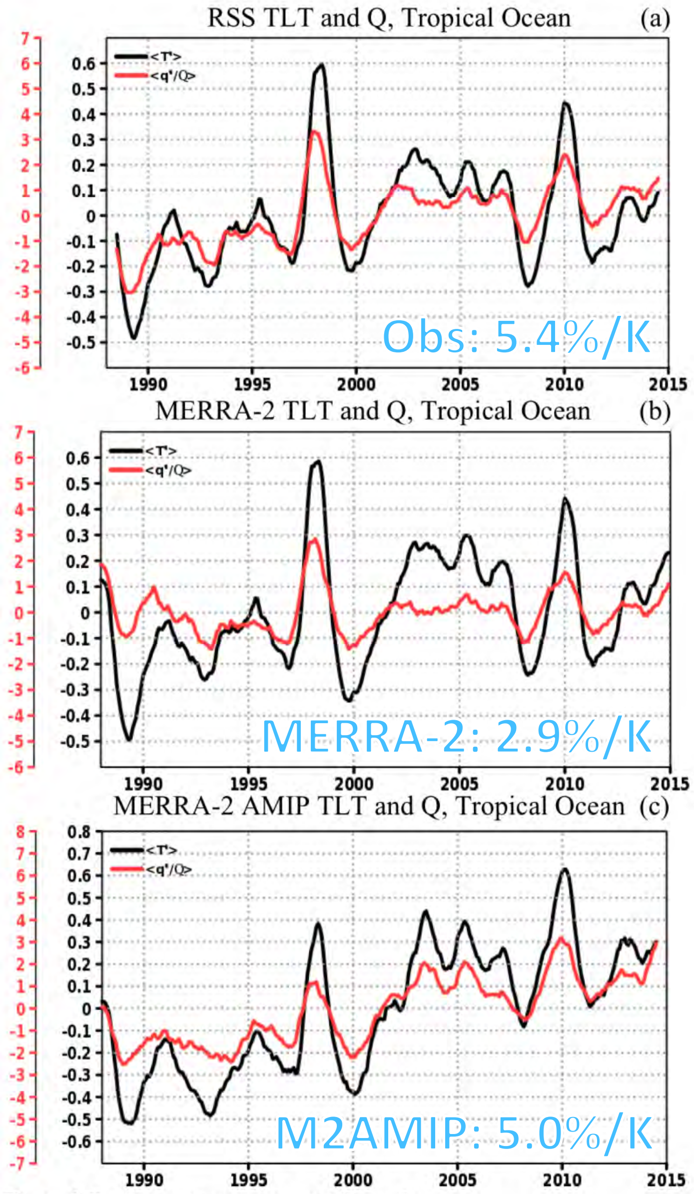
Produce 40-year datasets (1979-2018)：
–Ingested observations
–Reanalysis datasets: CMA Reanalysis (~30km, 6 hourly)
–Obs. feedback datasets：departure from analysis & 6h forecast
–Reanalysis uncertainty：from EnKF ensembles

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

国家气象信息中心
National Meteorological Information Center

Summary

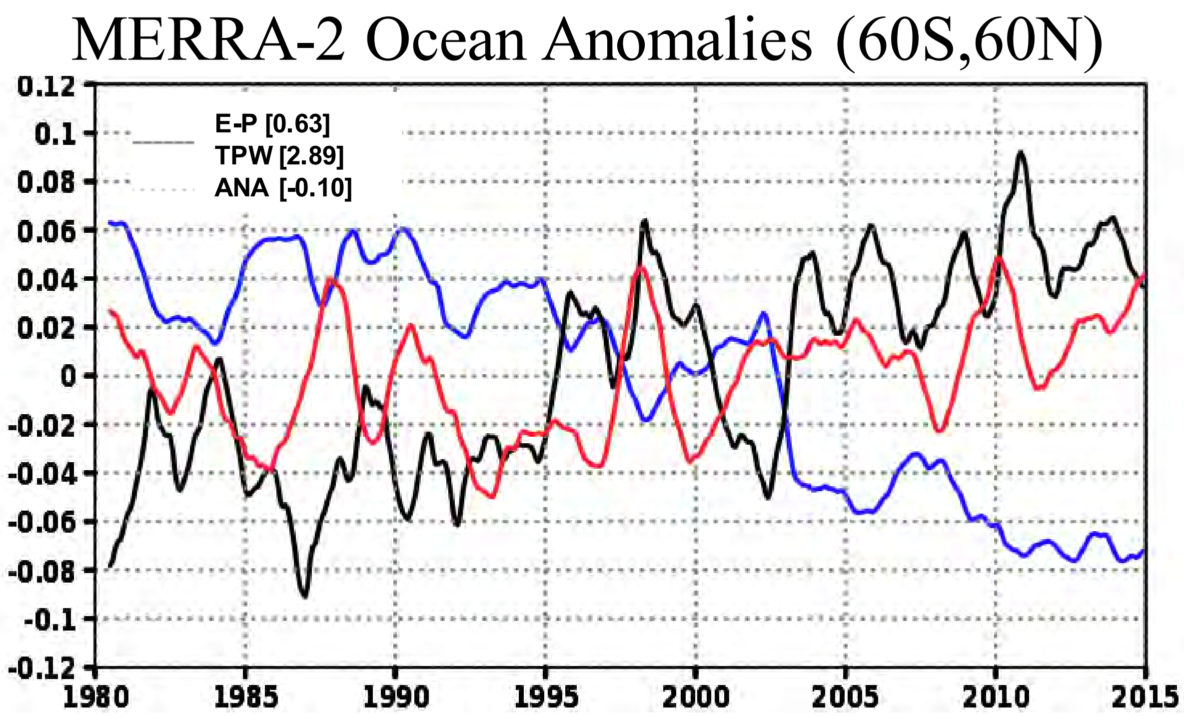
- Reanalysis Data Development is still going strong - Earth System coupling plans are moving forward
  - More important than ever for users to understand the reanalysis methodology and foundations
- Tools and data access are growing and improving
  - Users still need guidance on strengths and weaknesses
- 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, JClim); 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

System	T	Q	dT/dt	dQ/dt	%/K Detrend	%/K Trend	%/K S(Q)/S(T)	Corr(T,Q)
OBS	TLT	TPW	0.10	1.03	4.6	5.4	6.2	0.90
MERRA2	TLT	TPW	0.11	0.15	3.2	2.9	3.7	0.78
M2AMIP	TLT	TPW	0.28	1.53	4.5	5.0	7.1	0.97
MERRA2	T850	TPW	0.20	0.15	4.0	2.3	5.3	0.63
M2AMIP	T850	TPW	0.24	1.53	6.0	6.2	3.7	0.97
ERAI	T850	TPW	0.05	0.23	4.3	4.3	10.9	0.58
JRA55	T850	TPW	0.12	0.30	4.7	4.0	6.4	0.71
20CR	T850	TPW	0.13	0.84	6.8	6.7	6.4	0.95
ERA20C	T850	TPW	0.27	1.42	7.1	5.9	7.2	0.94
ERA20CM	T850	TPW	0.22	1.38	7.0	6.5	5.7	0.98

- 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)