

MERRA - NASA's Reanalysis Overview of the System

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&
GMAO

<http://gmao.gsfc.nasa.gov/merra>



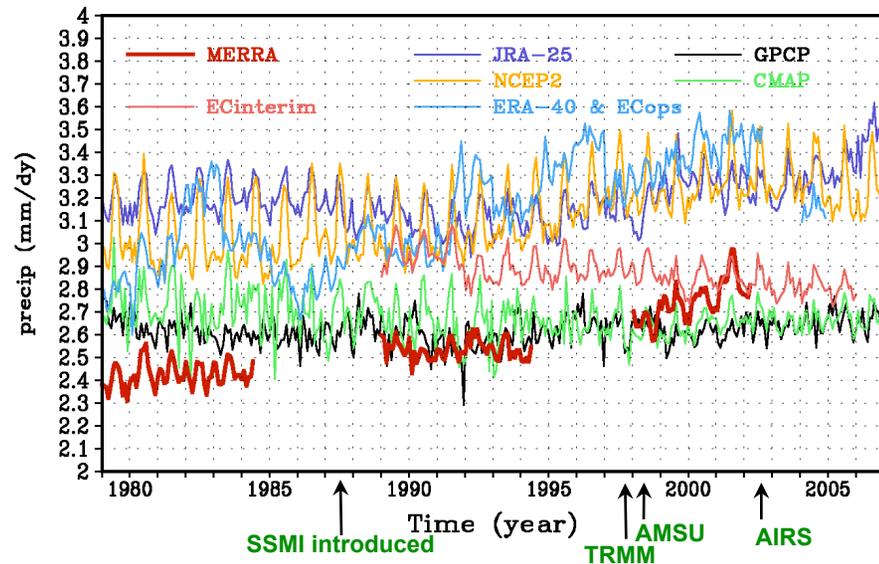
MERRA

The **M**odern **E**ra **R**etrospective-analysis for **R**esearch and **A**pplications is a reprocessing of atmospheric observations from **1979 to present** using the GEOS-5 Data Assimilation System.

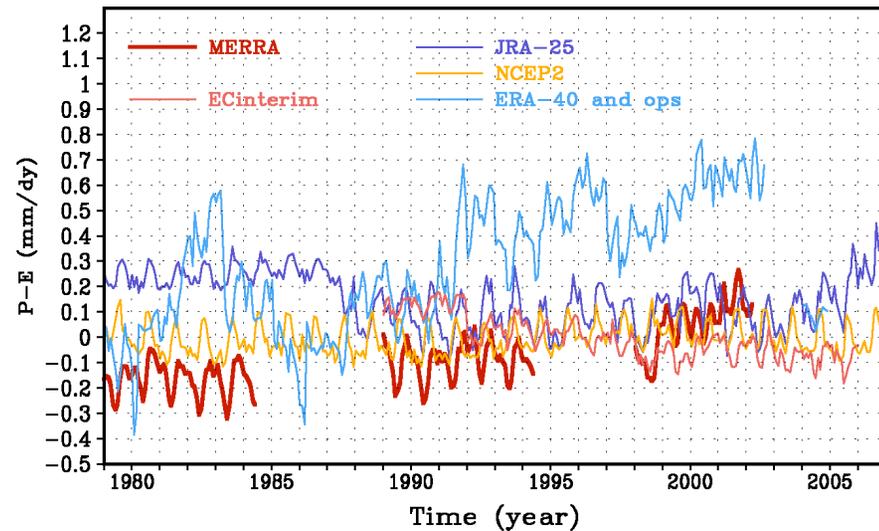
The focus of MERRA is the hydrological cycle.

Assimilation of the historical data stream: consistent Climate Data Records for several Essential Climate Variables concurrently.

Global mean precipitation

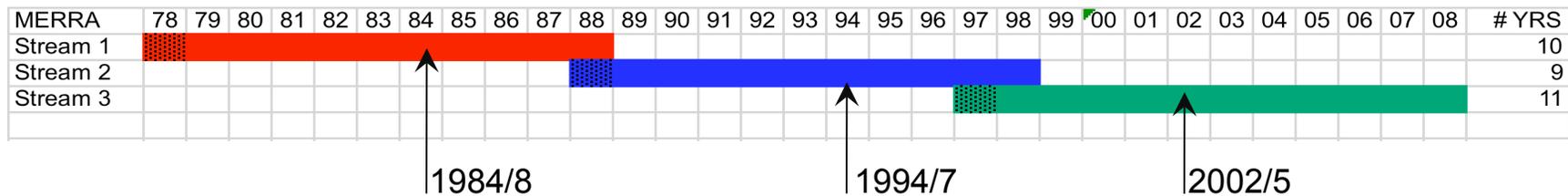


Global mean P-E



MERRA Production

- System version: GEOS-5.2.0
- 1979 – present
- $1/2^\circ \times 2/3^\circ \times 72L$
- 2-year spin up at 2-degree resolution
- 1-year spin up at $1/2$ degree
- Product Streams begin: Jan 1 – 1979, 1989 and 1998



• Preview/Validation runs:

- Jan, Apr, Jul, Oct 2004
- July-August 1987
- Jan, Jul 2001
- Jul 2006

- **2 degree (scout) runs** ⇒ preliminary look at data and spin-up of satellite bias estimates.

Validation Foci:

- Climate (comparisons with NCEP R1&R2, ERA-40, EC-Ops, JRA-25, CERES/ERBE TOA fluxes, GPCP precipitation, ..)
- Comparisons with satellite observations (CloudSAT, TRMM, SSMI, ...)
- Hydrological cycle (comparisons with GPCP, CEOP, ...)
- Land surface hydrology and energy balances
- Climate variability: Diurnal cycle, monsoons, ...
- Stratosphere, constituent transport, QBO
- Marine surface fluxes
- Budgets

Note: little attention to NWP skill scores in system tuning

GEOS-5 Atmospheric Data Assimilation System

AGCM

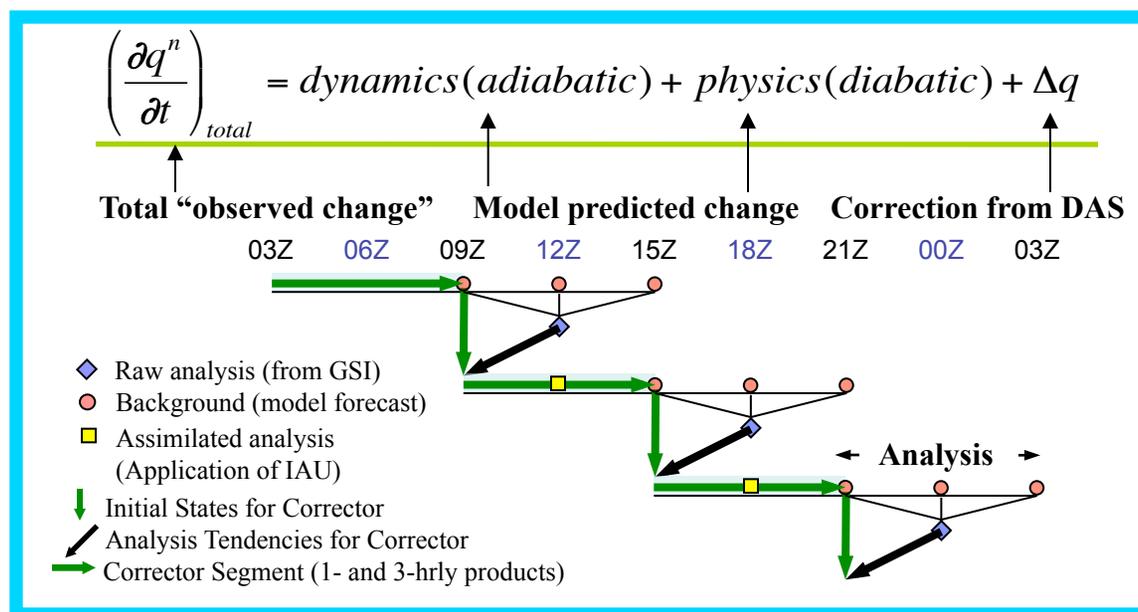
- Finite-volume dynamical core
- Integrated set of physics packages
- Physics integrated under the Earth System Modeling Framework (ESMF)
- Generalized vertical coord to 0.01 hPa
- Catchment land surface model
- Prescribed aerosols
- Interactive ozone
- Prescribed SST, sea-ice

Assimilation

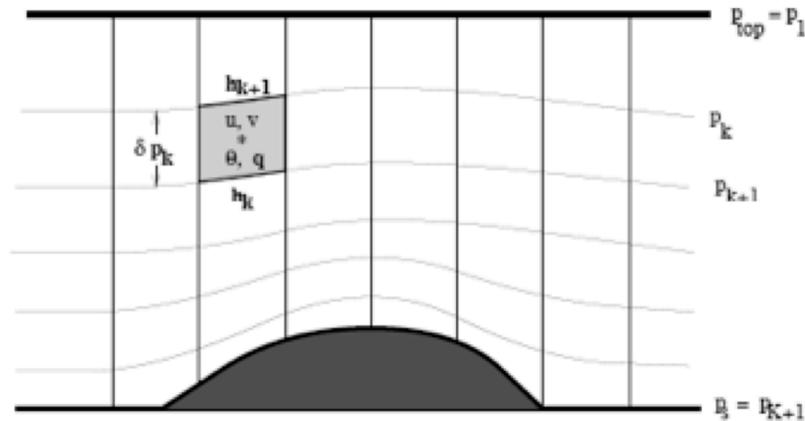
- Apply Incremental Analysis Increments (IAU) to reduce shock of data insertion
- IAU gradually forces the model integration throughout the 6 hour analysis period
- Provides a “replay” capability

Analysis

- Grid Point Statistical Interpolation - GSI (co-dev. with NCEP)
- Direct assimilation of satellite radiance data using JCSDA Community Radiative Transfer Model (CRTM)
- Variational bias correction for radiances



The GEOS-5 terrain-following Lagrangian control volume (lcv) coordinate system



GEOS-5_Moist

q, T

RAS

- Estimates plume mass fluxes
- Performs simple in-cloud microphysics
- Outputs:**
 - Detrained mass
 - Detrained condensate
 - Precipitating condensate profile

q^*, T^*
 $\delta q_{c, an}$
 $\delta q_{p, cu}$

PrognCloud

- Adds RAS detraining mass and condensate to anvil-type clouds
- PDF-based condensation produces large-scale clouds
- Evaporation and autoconversion remove fraction and condensate for anvil and large-scale clouds. Precipitating condensate created
- Precipitating condensates accumulated re-evaporated from top down

Radiation: Long-wave and Shortwave radiation from Chou et al.

PBL: modified Lock scheme; Louis scheme for stable bl

GWD: orographic (McFarlane) & non-orographic (Garcia and Boville)

Moist Physics for GEOS-5

Moist physics consists of RAS convection and large-scale cloud condensate scheme.

Two condensate phases:

liquid and ice

Two condensate “families”:

convective source, statistical source

Moist Physics State Variables (vapor, 4 condensates (q), 2 fractions (f))

RAS

outputs detrained mass and cloud condensates, precipitating condensate profiles, updated T,q,u,v, tracers

Prognostic Cloud scheme

inputs T, u, v, q's, f's, convective mass and condensate profiles

outputs updated T, q's, f's, rain rates

(post-processed for radiation)

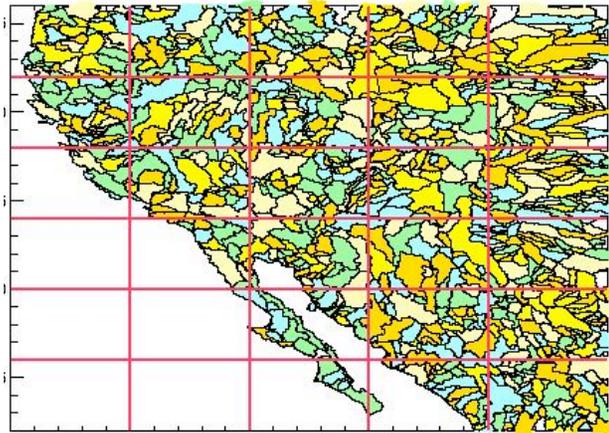
$f_{\text{tot}}, q_{\text{vap}}, q_{\text{ice}}, q_{\text{liq}}, R_{\text{ice}}, R_{\text{liq}}$

↑
Effective radii

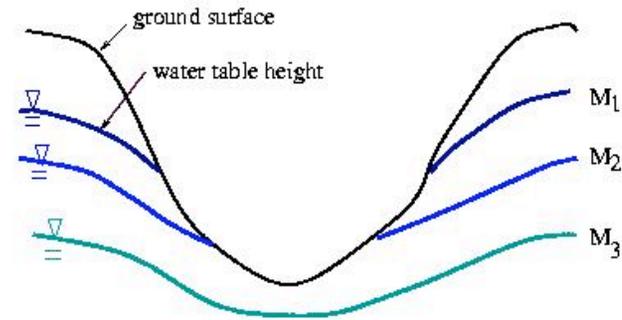
GEOS-5: The NASA Catchment LSM

APPROACH:

- Use the hydrological catchment as the fundamental land surface unit.
- Within each catchment, use hydrological models for dealing with topographic effects on subgrid soil moisture distributions.



SEPARATION OF CATCHMENT AREA INTO HYDROLOGICAL REGIMES

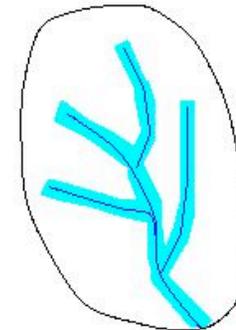


PLAN VIEW: M₁



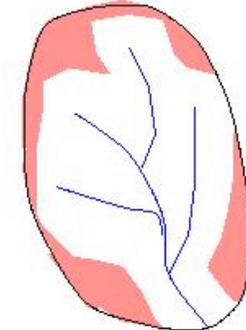
Significant saturated fraction leads to high surface runoff.

PLAN VIEW: M₂



Lower water table leads to smaller saturated fraction.

PLAN VIEW: M₃



Saturated fraction equals zero; part of catchment now below wilting point.

Snow: 3 prognostic variables (heat content, snow water equivalent, and snow depth) in each of 3 layers (Stieglitz et al., 2001).

The GSI analysis

$$J = \underbrace{J_b}_{\text{Fit to background}} + \underbrace{J_o}_{\text{Fit to observations}} + \underbrace{J_c}_{\text{constraints}}$$

$$J = (x_a - x_b)^T B^{-1} (x_a - x_b) + (h(x_a) - y)^T (E + F)^{-1} (h(x_a) - y) + J_C$$

| | | | |
|-------|---|-------|-----------------|
| x_a | = Analysis | x_b | = Background |
| y | = Observations | h | = Forward model |
| B | = Background error covariance | | |
| $E+F$ | = R = Instrument error + Representativeness error | | |

Implemented as a 3D-variational problem

Various minimization schemes (**Conjugate-gradient**, Qnewton, and Lanczos)

B: from GEOS-4, using “NMC method” – see Documentation for details

The GSI analysis is a joint development of NOAA/NCEP and NASA/GMAO

The GSI analysis (2)

$$J(\mathbf{x}) = (\mathbf{x} - \mathbf{x}_b)^T B^{-1}(\mathbf{x} - \mathbf{x}_b) + (b - b_b)^T B_b^{-1}(b - b_b) + [\mathbf{y} - h(\mathbf{x}) - b(\mathbf{x}, b)]^T R^{-1} [\mathbf{y} - h(\mathbf{x}) - b(\mathbf{x}, b)] + J_C$$

$$b(\mathbf{x}, b) = \sum_{i=0}^{N_p} \beta_i \mathbf{p}_i(\mathbf{x})$$

b is the bias model and the \mathbf{p}_i are the predictors

The predictor coefficients are different for each channel and each sensor

\mathbf{p}_0 is a constant

Other predictors: scan angle, lapse rate, lapse rate squared and cloud liquid water (MW)

Analysis control variables

| | |
|----------------|--|
| ψ | stream function contribution to wind |
| χ_{unbal} | unbalanced velocity potential function |
| T_{unbal} | unbalanced temperature |
| P_{unbal} | unbalanced surface pressure |
| q | moisture |
| c_w | cloud water |
| O_3 | ozone |

| |
|----------------------|
| $T_{bal} = G\psi$ |
| $\chi_{bal} = C\psi$ |
| $P_{bal} = W\psi$ |

Coefficients for the bias correction of the satellite radiance data

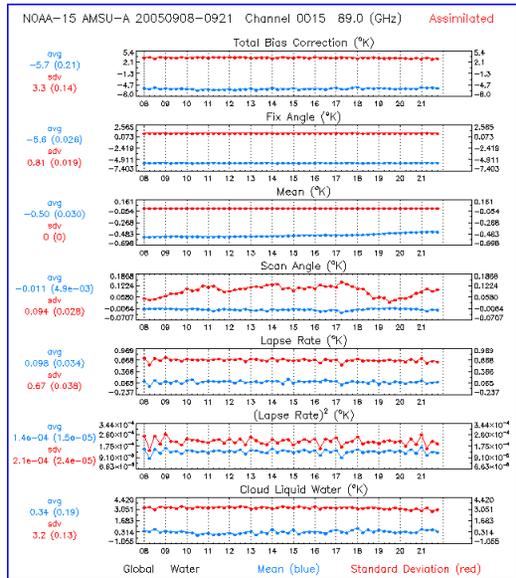
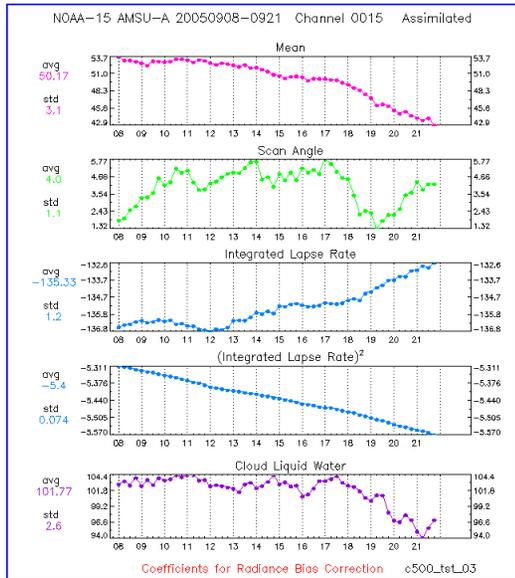
Rain rate is NOT a control variable

$$rain_rate_{tot} = rain_rate_{convective}(T, u, v, q, p_s) + rain_rate_{large-scale}(T, q, c_w, p_s).$$

Variation bias correction for satellite radiances

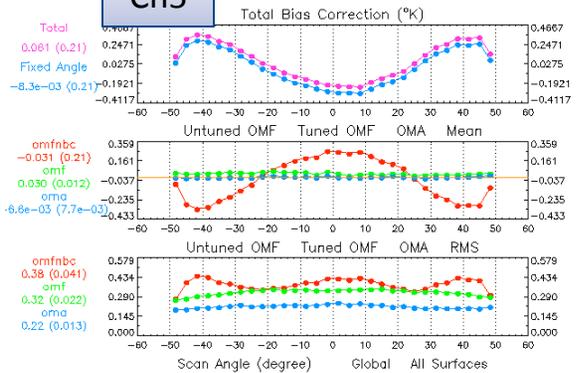
Example of Coefficients for N15 AMSU-A Ch15

Contributions to bias correction for N15 AMSU-A Ch15

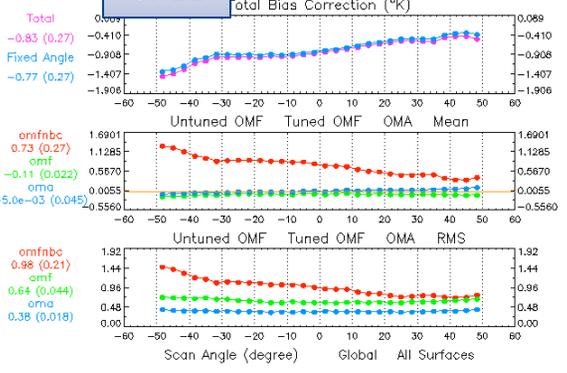


Scan angle dependence of Coefficients for N16 AMSU-A Ch5 and Ch12

Ch5



Ch12



Radiosonde Data Corrections

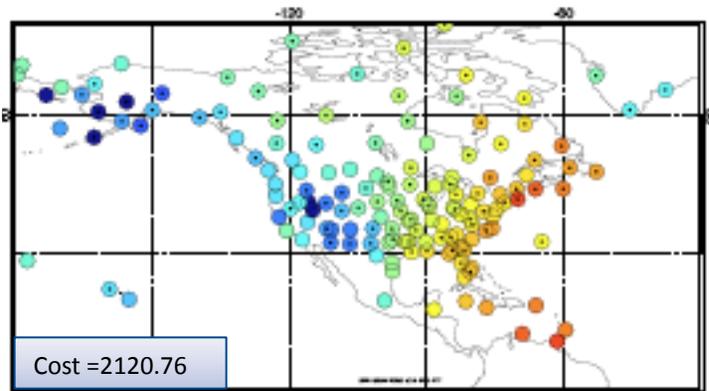
The radiosonde temperature observations undergo up to three adjustments to remove or reduce biases.

1. Unrealistically large 00/12 UTC time-mean temperature differences from NWS radiosonde observing stations that launch Vaisala RS-80 radiosondes are removed according to Redder et al. (2004)
2. Temperatures are adjusted according to the homogenization scheme (i.e. the removal of artificial changes in time-series) of Haimberger (2007)
3. Temperatures are adjusted to account for the effects of seasonal changes in the sun's elevation angle and, therefore, radiation bias of the thermistor.

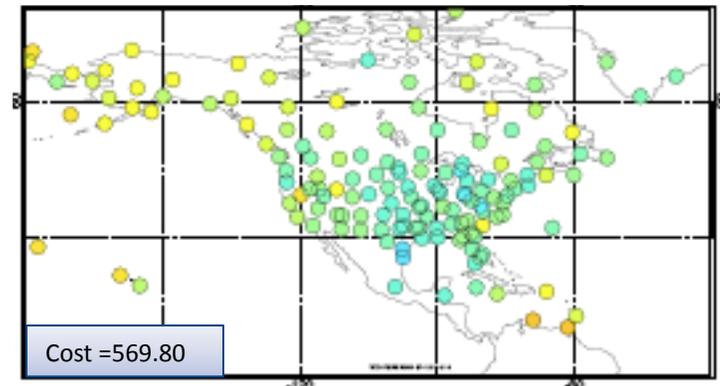
Temperature Difference 00h 1989-1990 50 hPa [K], 12h-00h

After Adjustment with RAOBCORE

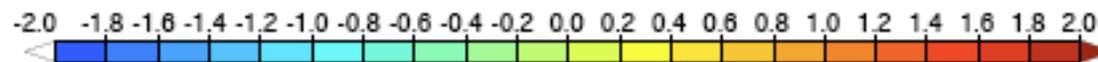
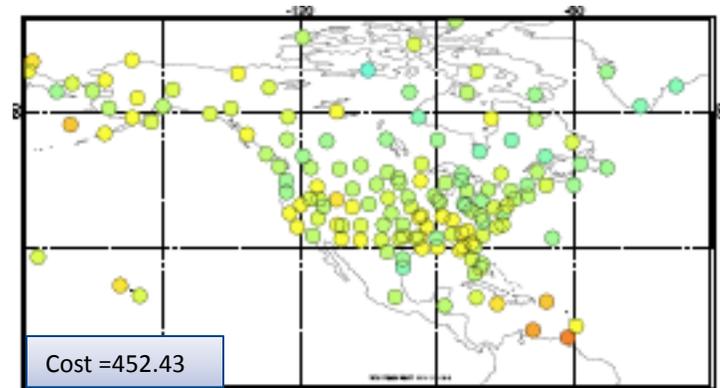
Before Adjustment with RAOBCORE



Using NWS Vaisala corrections



Using GMAO Vaisala corrections



From Leo Haimberger

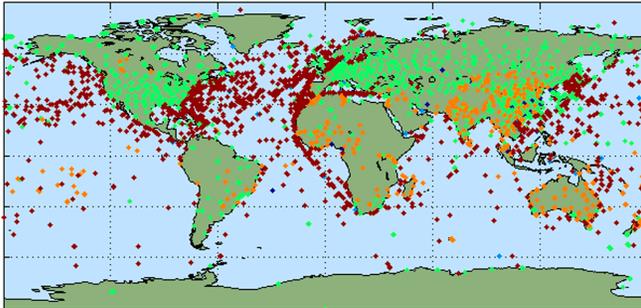
| DATA SOURCE/TYPE | PERIOD | DATA SUPPLIER |
|---|-------------------------|----------------------|
| Conventional Data | | |
| Radiosondes | 1970 - present | NOAA/NCEP |
| PIBAL winds | 1970 - present | NOAA/NCEP |
| Wind profiles | 1992/5/14 - present | UCAR CDAS |
| Conventional, ASDAR, and MDCRS aircraft reports | 1970 - present | NOAA/NCEP |
| Dropsondes | 1970 - present | NOAA/NCEP |
| PAOB | 1978 - present | NCEP CDAS |
| GMS, METEOSAT, cloud drift IR and visible winds | 1977 - present | NOAA/NCEP |
| GOES cloud drift winds | 1997 - present | NOAA/NCEP |
| EOS/Terra/MODIS winds | 2002/7/01 - present | NOAA/NCEP |
| EOS/Aqua/MODIS winds | 2003/9/01 - present | NOAA/NCEP |
| Surface land observations | 1970 - present | NOAA/NCEP |
| Surface ship and buoy observations | 1977 - present | NOAA/NCEP |
| SSM/I rain rate | 1987/7 - present | NASA/GSFC |
| SSM/I V6 wind speed | 1987/7 - present | RSS |
| TMI rain rate | 1997/12 - present | NASA/GSFC |
| QuikSCAT surface winds | 1999/7 - present | JPL |
| ERS-1 surface winds | 1991/8/5 - 1996/5/21 | CERSAT |
| ERS-2 surface winds | 1996/3/19 - 2001/1/17 | CERSAT |
| Satellite Data | | |
| TOVS (TIROS N, N-6, N-7, N-8) | 1978/10/30 - 1985/01/01 | NCAR |
| (A)TOVS (N-9; N-10 ; N-11; N-12) | 1985/01/01 - 1997/07/14 | NOAA/NESDIS & NCAR |
| ATOVS (N-14; N-15; N-16; N-18; N-18) | 1995/01/19 - present | NOAA/NESDIS |
| EOS/Aqua | 2002/10 - present | NOAA/NESDIS |
| SSM/I V6 (F08, F10, F11, F13, F14, F15) | 1987/7 - present | RSS |
| GOES sounder T _B | 2001/01 - present | NOAA/NCEP |
| SBUV2 ozone (Version 8 retrievals) | 1978/10 - present | NASA/GSFC/Code 613.3 |

A special thanks to Jack Woollen of NOAA/NCEP for help with the conventional data streams!!!!

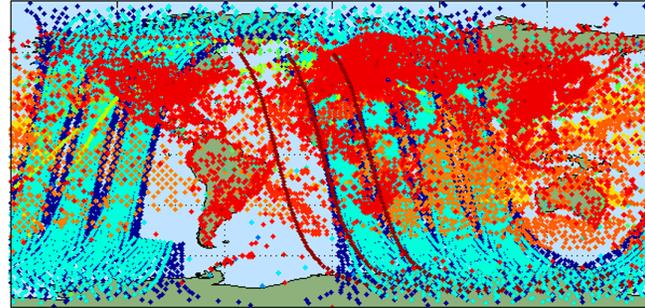
The Changing Observing System through MERRA

The number of observations in a 6-hour assimilation window

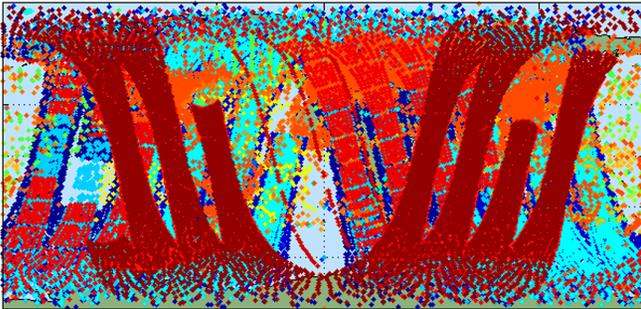
12 UTC, 7 January 1973: 77,098 obs



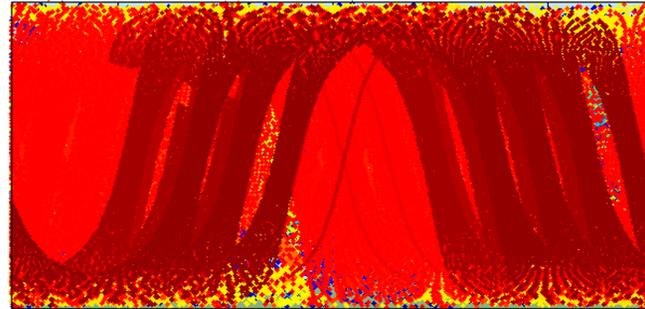
12 UTC, 7 January 1979: 325,765 obs



12 UTC, 2 August 1987: 550,602 obs



12 UTC, 7 January 2006: 4,217,655 obs



MERRA FILE COLLECTIONS

- Distributed through a modeling data portal at the Goddard DISC:
<http://disc.sci.gsfc.nasa.gov/MDISC/>
- MERRA products are organized into **24 collections** in HDF
- All distributed data products have slightly degraded precision and are compressed with gzip.
- Data are produced on three horizontal grids:
 - Native ----- (1/2 by 2/3 w/ FV conventions)
 - Reduced ----- (1.25 by 1.25 Dateline-edge, Pole-edge)
 - Reduced FV -- (1 by 1¼ w/ FV conventions)
- In the vertical, 3-D data are on:
 - 72 model layers
 - 42 pressure levels
- Diagnostics temporal resolution:
 - 3D products are 3-hourly
 - 2D products are hourly
- Total online collections ~70TB

http://gmao.gsfc.nasa.gov/research/merra/MERRA_FileSpec_DRAFT_09_02_2008.pdf

MERRA FILE COLLECTIONS

ANALYZED FIELDS (u,v,t,q,O₃,p) [2]
NATIVE, INSTANTANEOUS, 6-HOURLY
MODEL AND PRESSURE LEVELS

INVARIANTS [2]

ASSIMILATED FIELDS [1]
REDUCED, INSTANTANEOUS, 3-HOURLY
PRESSURE LEVELS

3-D DIAGNOSTIC FIELDS [8]
REDUCED, TIME-AVERAGED, 3-HOURLY
PRESSURE LEVELS

2-D DIAGNOSTIC FIELDS [5]
NATIVE, TIME-AVERAGED, HOURLY

**PRODUCTS FOR OFFLINE
CHEMISTRY TRANSPORT MODELS** [6]
VARIOUS RESOLUTIONS FREQUENCIES AND GRIDS

MERRA Documentation

Available on the MERRA website

- GEOS5 Model and Assimilation Document, Rienecker et al., 2008: NASA/TM-2008-104606, V27
- MERRA File Specification, Suarez et al. (Outlines the output data format, and information on variables)

http://gmao.gsfc.nasa.gov/research/merra/MERRA_FileSpec_DRAFT_09_02_2008.pdf

- MERRA Validation, Bosilovich et al. (Results of the GEOS5 Validation Experiments, prior to beginning MERRA production)

To finish....

- ~ 50% complete mid-January 2009
- Expect to complete processing to end of 2007 by August 2009
- Will continue forward as a CDAS
- Future plans: using GEOS-5 replay capability to couple MERRA with ocean, aerosols, other atmospheric constituents, land surface
- MERRA is the first part of NASA's contribution to a national strategy for reanalysis – use of the data and feedback from users will be important to frame the next reanalysis
- MERRA and CFSRR – benefit from collaborations on input data and early evaluations of the system

ACKNOWLEDGMENTS

- NCEP, NESDIS – for GSI and CRTM for historical data streams
- Peter Colarco (with Arlindo da Silva) for aerosol distributions
- Code 613.3 for SBUV, V8
- NCCS for tremendous support for production queues
- SIVO for help with performance issues
- GES DISC for the MDISC and support in online product distribution
- External User Group for evaluation of early products and guidance on products
- Don Anderson & Tsengdar Lee for programmatic and moral support