NASA MERRA-2 Global Modeling System

Modern-Era Retrospective analysis for Research and Applications, Version 2 (MERRA-2)

data assimilation : measurements of various components of the state of the atmosphere at a
given time that are combined with a three-dimensional gridded representation of atmospheric elds obtained
from a general circulation model integration. This is done in a statistically optimal way, by taking into account observational and model forecast errors.

Analysis : The blended new set of elds that is then used to generate an initial condition for a short (here 6-hourly) model forecast which produces the background elds for the next assimilation cycle.

Undertaken by NASA's Global Modeling and Assimilation Office (GMAO)

Two primary objectives:

1) Place observations from NASA's Earth Observing System (EOS) satellites into a climate context

2) Update MERRA system to include the most recent satellite data.

Produced using :

- GEOS-5 atmospheric model and data assimilation system,
- the three-dimensional variational data analysis (3DVAR) and Gridpoint Statistical Interpolation (GSI) meteorological analysis scheme

Incremental analysis update procedure every 6 h.

Resolution on a cubed-sphere grid ~50 km with 72 layers from the surface to 0.01 hPa

Accessing and processing the data

- NASA provides an online map of worldwide atmospheric parameters :

https://worldview.earthdata.nasa.gov/?p=geographic&l=VIIRS_SNPP_CorrectedReflectance_TrueColor(hidden),MODIS_Aqua_CorrectedReflectance_TrueColor(hidden),MODIS_Terra_CorrectedReflectance_TrueColor,MODIS_Terra_Aerosol,Reference_Labels,Reference_Features,Coastlines&t=2017-05-02&z=3&v=-125.4375,-48.8671875,81.84375,55.3359375

- All data can be access from this website :

https://disc.sci.gsfc.nasa.gov/datasets?page=1&keywords=MERRA-2

- Open an account is required to access the data :

https://urs.earthdata.nasa.gov/users/new?client_id=C_kKX7TXHiCUqzt352ZwTQ&redirect_uri=https%3A%2F%2Fdisc.sci.gsfc.nasa.gov%2Flogin%2Fcallback&response_type=code

The list of files and their variables are described in this publication :

https://gmao.gsfc.nasa.gov/pubs/docs/Bosilovich785.pdf

- Ascii and nc4 Files format are available :

An ipynb from Sylvie on how to look at the nc4 using the python library h5py is available at :

https://github.com/sylvielsstfr/GMAOMERRA2/blob/master/inst1_2d_asm_Nx_M2I1NXASM/MERRA2_inst1_2d_asm_Nx_M2I1NXASM.ipynb

Analysis

- Python script for extracting maps, making a movie and interpolation above a given location (ctio or ohp):
- merra2-chain.py
- For exemple : merra2-chain.py --site CTIO --value TQV --files <files>

- Exemples of movies around CTIO during October 2017, and temporal variation during the last 10 years are shown on the child page :
- Merra-2 Movies October 2017

The informations that we extract are the followings :

- CTIO seats on a large east-west PWV gradient.

- PWV and Ozone follow circadian variations.
- PWV and Ozone are anti-correlated on an annual basis.
- Large variations of AOD, PWV and Ozone can sometimes occur within a few hours timespan.
- O3 and PWV gradients go along the same direction, both at CTIO and Mauna Kea.

Questions that we want to answer :

- Make movies of the clouds / extract clouds OD.
- Determine the spatial gradient on a line of sight above CTIO.
- Many tables exhibits a 6h frequency oscillation : Is it real or is it a pattern injected by the assimilation that is also on a 6h timeline ?

To Do :

- [x] Copy the data at NCSA.   (03.27.2018) Data are on the NCSA servers @ /lsst/project/ctio_meteo

Documentation

- publication on MERRA-2 :

  https://journals.ametsoc.org/topic/merra-2

- publication on MODIS :

  https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20030025758.pdf

  ### Abstract

  The Moderate Resolution Imaging Spectroradiometer (MODIS) is an earth-viewing sensor that flies on the Earth Observing System (EOS) Terra and Aqua satellites, launched in 1999 and 2002, respectively. MODIS scans a swath width of 2330 km that is sufficiently wide to provide nearly complete global coverage every two days from a polar-orbiting, sun-synchronous, platform at an altitude of 705 km. MODIS provides images in 36 spectral bands between 0.415 and 14.235 pm with spatial resolutions of 250 m (2 bands), 500 m (5 bands) and 1000 m (29 bands). These bands have been carefully selected to enable advanced studies of land, ocean, and atmospheric properties. Twenty-six bands are used to derive atmospheric properties such as cloud mask, atmospheric profiles, aerosol properties, total precipitable water, and cloud properties. In this paper we describe each of these atmospheric data products, including characteristics of each of these products such as file size, spatial resolution used in producing the product, and data availability.

  "The accuracy of satellite estimates of aerosol optical thickness was first suggested based on theoretical analyses [9], [25], and consisted of a bias of f0.05 over land and f0.03 over ocean due to uncertainty in the estimate of surface reflectance"   **p.13**

- **Monitoring the atmospheric throughput at Cerro Tololo InterAmerican Observatory with aTmCam**

  https://arxiv.org/pdf/1407.7047.pdf

  "PWV can change by a few millimeters over one night and mostly decreases over time on any given night"

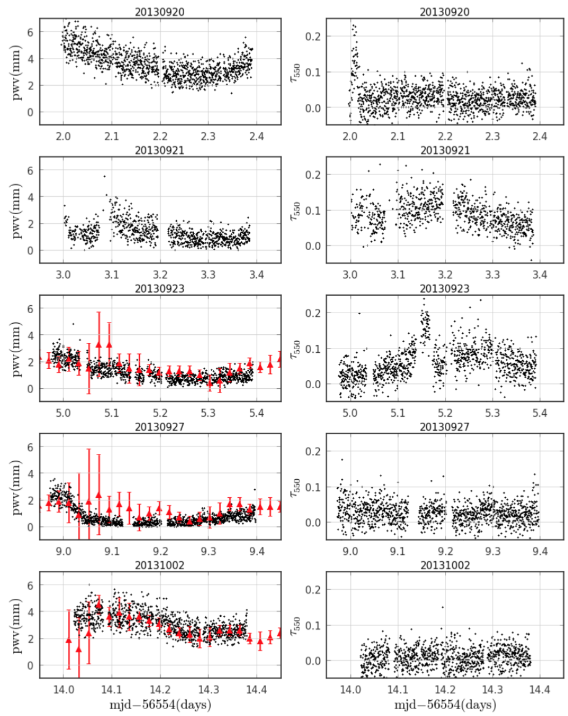

Figure 5: An example of 5 nights of the results from 2013 observing run. The left (right) column shows the PWV (AOD) as a function of time in MJD. The number on the top of each panel is the date of the night that the observation started, in the format of YYYYMMDD. Overplotted red triangles are the PWV measured by a GPS Water Vapor Monitoring System.

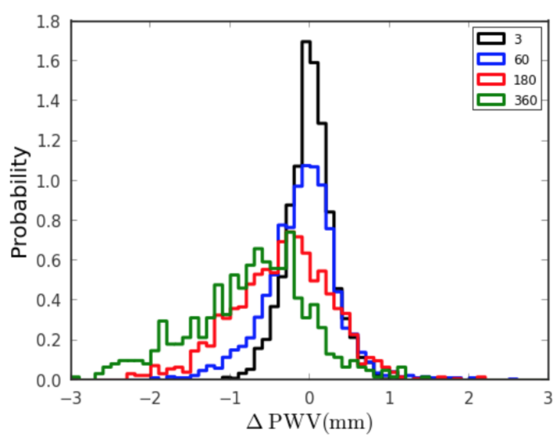

Figure 7: The distribution of ΔPWV in 3 minutes, 1 hour, 3 hours, and 6 hours.

Assuming there is no variation in 3 mn, the precision of the measurement is given by the sigma of the black histogram : 0.3 mm uncertainty on the measurement.

From their dataset, the authors conclude that a 1 mm monitoring imply an hourly sampling.

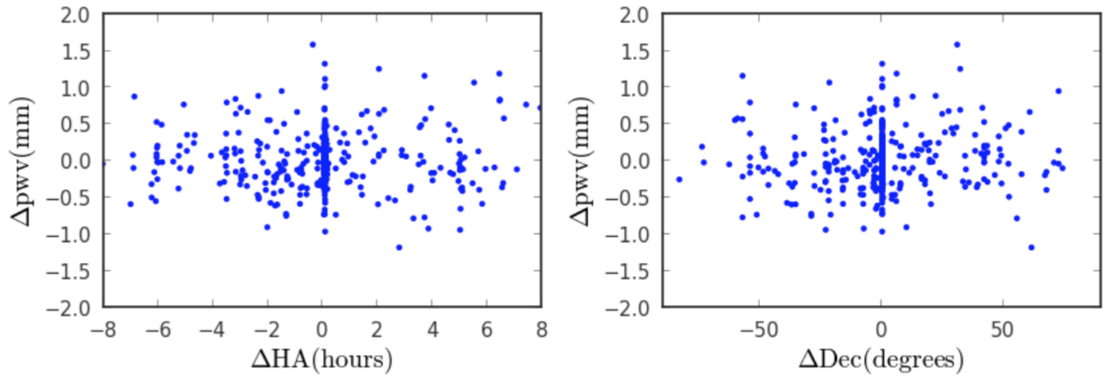

Figure 12: Angular variation of the PWV as a function of east-west (left) and north-south (right) pointing of the telescope. No obvious trend of an east-west or north-south gradient was found during the 2013 observing run.

The authors report no detection of spatial gradient. From MERRA-2 0.1 mm could be expected, which is below the sensitivity of their observations.

- **Operational optical turbulence forecast for the Service Mode of top-class ground based telescopes**
- **https://arxiv.org/abs/1608.06506**

- **SCUBA-2: on-sky calibration using submillimetre standard sources**
- **https://academic.oup.com/mnras/article/430/4/2534/110341**
- **Atmospheric extinction properties above Mauna Kea from the Nearby Supernova Factory spectro-photometric data set** (SNFactory) Button et al 2012
- https://arxiv.org/pdf/1210.2619.pdf

- **The MERRA-2 Aerosol Reanalysis, 1980 Onward. Part I: System Description and Data Assimilation Evaluation**
- **https://journals.ametsoc.org/doi/pdf/10.1175/JCLI-D-16-0609.1**

- **The MERRA-2 Aerosol Assimilation**
- **https://gmao.gsfc.nasa.gov/pubs/docs/Randles887.pdf**

- **MERRA-2 Input Observations: Summary and Assessment**
  https://gmao.gsfc.nasa.gov/pubs/docs/McCarty885.pdf

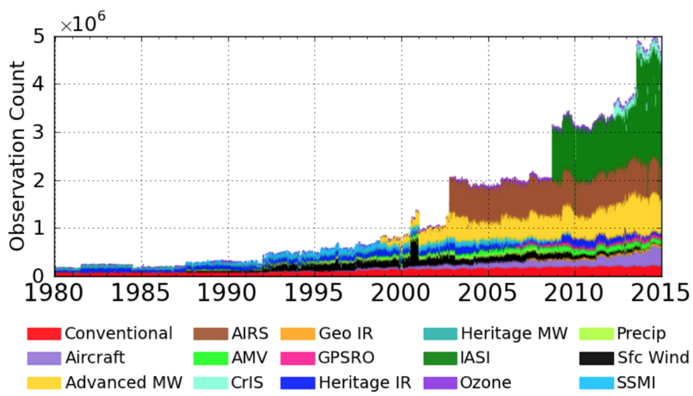

Figure 1 - Time series of assimilated observations for MERRA-2 for 1 January 1980 – 31 December 2014

- **The global structure of upper troposphere-lower stratosphere ozone in GEOS-5 : A multiyear assimilation of EOS Aura data**
  https://agupubs.onlinelibrary.wiley.com/doi/epdf/10.1002/2014JD022493

- **A better understanding of cloud optical thickness derived from the passive sensors MODIS/AQUA and POLDER/PARASOL in the A-Train constellation**

https://www.atmos-chem-phys.net/12/11245/2012/acp-12-11245-2012.pdf

- **Optical atmospheric extinction over Cerro Paranal**

https://arxiv.org/pdf/1011.6156.pdf

- **3D numerical simulations of optical turbulence at the Roque de Los Muchachos Observatory using the atmospherical model Meso-Nh**

https://www.aanda.org/articles/aa/pdf/2001/03/aa10007.pdf

- **Precipitable water vapour forecasting: a tool for optimizing IR observations at Roque de los Muchachos Observatory.**
  https://arxiv.org/pdf/1804.05200.pdf

- **Model of optical turbulence profile at Cerro Pachon**
  365-4-1235.pdf

- **Astronomical site selection: On the use of satellite data fo r aerosol content monitoring**

  http://lanl.arxiv.org/pdf/0810.0927v1

- **Validation of libRadtran and SBDART models under different aerosol conditions**
  http://iopscience.iop.org/article/10.1088/1755-1315/28/1/012010/pdf

- **PWV KPNO: A PYTHON PACKAGE FOR MODELING THE ATMOSPHERIC TRANSMISSION FUNCTION DUE TO PRECIPITABLE WATER VAPOR**

  https://arxiv.org/pdf/1806.09701.pdf

It uses PWV from SuomiNet which is referenced at CTIO, though not working as of today (June 27th 2018).

Also, it cannot be used as is by LSST, as it has built in MODTRAN curves from Kitt Peak only.

- **Assessment and applications of NASA ozone data products derived from Aura OMI/MLS satellite measurements in context of the GMI ch emical transport model**

https://agupubs.onlinelibrary.wiley.com/doi/epdf/10.1002/2013JD020914

- **The global structure of upper tropospher e-lower stratosphere ozone in GEOS-5 : A multiyear assimilation of EOS Aura data**

https://agupubs.onlinelibrary.wiley.com/doi/epdf/10.1002/2014JD022493