OSCAR: Online Services for Correcting Atmosphere in Radar

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Tropospheric water vapor

• Water vapor delay of radar propagation is non-dispersive in troposphere
• Large temporal and spatial variability
  – Seasonal and weather-induced.
  – Power-law dependent decreasing power at shorter distances.
• Changes in stratified water vapor vertical gradient and dry atmospheric pressure cause delays correlated with topography
• Atmospheric corrections can be derived from
  – Weather-forecast models
  – Atmospheric data sets
  – GPS data
  – Self-consistent InSAR analysis
Example of tropospheric water vapor correction
# InSAR tropospheric water vapor corrections

- **Time series filtering or estimation**
- **Correlation of phase with topography**
- **CGPS (Continuous Global Positioning System) zenith wet delay interpolated spatially (and temporally)**
- **Total column water vapor from absorption of reflected near IR (MODIS and MERIS)**
- **Water vapor measurements (profiling and total column) from thermal IR and MW (AIRS, MODIS, AMSU)**
- **European Center for Medium Range Weather Forecasting (ECMWF)**
- **NOAA NCEP North American Mesoscale Model (NAM)**
- **OSCAR** is a web service that locates, retrieves, and merges these data sets to derive an optimal, best estimate of tropospheric delay
Atmospheric Data Sets

• MODIS near-IR total precipitable water vapor
  – Quality control, error characterization, bias corrections and remapping

• ECMWF Global Analysis
  – Bias correction, remapping and topography correction

• **Goal:** To combine data sets using Bayesian statistics.
  – Requires error estimates, which must be inferred empirically
MODIS water vapor correction model

Basic principles

• There is a scale uncertainty in MODIS near-IR water vapor products
• Only one continuous GPS station is required to calibrate MODIS scale uncertainty within a 2,030 km × 1,354 km MODIS scene
• GPS and MODIS data can be integrated to provide regional water vapor fields with a spatial resolution of 1 km × 1 km

References


Li, Z., J.-P. Muller, P. Cross, and E.J. Fielding (2005), Interferometric synthetic aperture radar (InSAR) atmospheric correction: GPS, Moderate Resolution Imaging Spectroradiometer (MODIS), and InSAR integration, JGR, 110 (B3), B03410.
ECMWF Forecast/Analysis Data

- Global operational deterministic weather forecast model
  - ¼°, 90 vertical levels (17 levels in boundary layer)
  - Increasing to 1/8° in W09, ½° prior to S06
  - Assimilation of satellite, ground, radiosonde and ship and aircraft observation

- Proprietary, but made available to this research activity provided
  - Original data is not redistributed
  - Sourced from JPL through Aqua/NPP agreements (no new data transfer costs)
  - Research only with appropriate acknowledgements

500 hPa wave height
28 Oct 2008 – Extreme weather event
Summary of InSAR Delay Correction Algorithms

General

\[ \varphi = \frac{k_0}{\cos \theta} \int_{z_s}^{\infty} \left[ k_1 \frac{P}{T} + W \frac{P}{T} \left( \frac{k_2}{T} + \frac{k_3}{T} \right) \right] dz \]

The wet and dry atmospheric delays are related to surface pressure \((P)\), surface elevation \((z_s)\), viewing angle \((\theta)\) and temperature and water vapor profiles \((T,W)\).

MODIS

Estimate of delay \( D = A w \)

At present, constant \( A=6.2 \) determined from comparison with GPS zenith total delay \((\text{Li et al., 2005})\), \( w \) is the MODIS NIR total precipitable water vapor

ECMWF

Estimate of delay \( D = \sum_{i=1}^{N} 2\pi d_i^{SBL} \left( n_i^{(\text{vapor})} - n_i^{(\text{dry})} \right) \)

The layer thicknesses \( d_i^{SBL} \) are obtained by correcting the original thicknesses in the ECMWF model by using the correct topography

\[ d_i^{SBL} = \frac{D_i^{BL,SRTM}}{D_i^{BL,ECMWF}} d_i^{ECMWF} \]

Using multiple data sets with height registered temperature and water vapor, delays from integrated products, such as the MODIS total precipitable water vapor, can be used in the general delay equation to provide more accurate delay estimates.
MODIS Quality Control Model

Basic principles

- Comparison of MODIS NIR water vapor with GPS, radiosondes and AERONET Sun photometer, clear pixels
  - RMS differences ($\sigma$) 5.44 kg/m$^2$ at 1 km spatial resolution

- Unusable over clouds
  - product is precise, but inaccurate because it misses column below the cloud

- Imprecise over water
  - Weak reflected signal, but not important for InSAR which is over land

- Unreported over heterogeneous surface, glint ....
  - indicated by fill value and *Quality_Assurance_Near_Infrared* parameter

- Quality degrades near low Q/A identified pixels, but not reported as low Q/A or cloudy.
Quality-controlled MODIS NIR Water Vapor

Low values adjacent to Q/C region are probably inaccurate although not flagged as such.
ECMWF Topographic Corrections

- Coarse spatial resolution of ECMWF topography introduces errors in local water vapor which can be corrected through a local topography correction.
Numerical Weather Forecast Topography Correction Models

- Hypotheses on scales at which approximation is applied:
  - No local sources of water vapor
  - No adiabatic heating or cooling

- Stretched Boundary Layer Approximation
  - Surface water vapor mixing ratio and temperature along surface is conserved
  - Flow is along slope
  - Free troposphere structure unperturbed by topography

- Truncated Boundary Layer Approximation
  - Flow is around obstacles
  - Profile is cut-off by ascending slopes
  - Depressions fill with uniform surface water vapor mixing ratio air.
Analysis and Validation of Correction Algorithms

- Use GPS ground stations with meteorology packages
- Sort stations by model elevation error
- Compare surface pressure and total precipitable water vapor before and after stretched boundary layer correction
Validation of Topography Correction Models

Time Series

- Comparison of GPS and corrected and uncorrected ECMWF water vapor
- Time series show strong seasonal component to error
  - 1-week moving window averaging applied
- SBL tends to under correct while TBL tends to over corrects
ECMWF Bias Correction Models

- ECMWF validation shows a 5.5% dry bias
- Topographic correction validation studies shows regional and seasonal bias between ECMWF and MODIS water vapor
- Water vapor is modulated by topography
  - A fixed bias correction produces negative total water vapor at high elevation.
- Appropriate bias correction should be a scaling factor
  - Dynamic
  - Derived from coincident, collocated data
ECMWF Bias Correction Algorithm

- Remap topographically corrected ECMWF and MODIS data to a common grid.
- Ratio median ECMWF to median MODIS water vapor in 2° lon-lat bins to produce scaling correction $f$
  - MODIS Q/C mask is 1
- Apply annealing algorithm to extend $f$ to empty bins
  - Iteratively extend $f$ into empty bins using median of $f$ in eight surrounding bins
- Bilinear interpolate $f$ to 0.005° regular grid
Remapping

MODIS

ECMWF

12 Mar 2010

16 Apr 2010

25 June 2010
Merging Algorithm

- Bayesian algorithm, average of MODIS and ECMWF water vapor weighted by square errors
- Bias-corrected, topographically corrected ECMWF water vapor has constant error.
- MODIS error is 2x ECMWF error, but
  - Spatial resolution of MODIS is 25x higher
  - At same spatial resolution, MODIS error is 12.5x smaller
- Smooth MODIS qc_mask to same resolution as ECMWF
  - Grid MODIS qc_mask to 0.005° grid
  - Run a 50x50 (0.25° wide) box car smoothing to gridded qc_mask
- Use the following error model error model

\[
\frac{\sigma_{\text{ECMWF}}^2}{\sigma_{\text{MODIS}}^2} = \frac{\text{smoothed_qc_mask}}{1 - \text{smoothed_qc_mask}}
\]
Example  Baja California  16 Apr 2010

Q/C’d MODIS

ECMWF

Merged

MODIS Wgt

Bias Factor
Example  Baja California  29 Aug 2008

Q/C’d MODIS

ECMWF

Merged

- Q/C MODIS shows striping
- 60 kg/m² corresponds to 36 cm of InSAR path delay.
Functional Architecture Diagram

clients

workflow

space, time

MODIS granules

MODIS delay

MODIS delay 10 arc sec

delay image

STQ: space - time query

SAM: MODIS subset & merge

IZPD: MODIS delay generation

ECMWF delay

ECMWF delay 10 arc sec

services

STQ

SAM

IZPD

ECG

RMP

MRG

flexible mapping to a network of servers

ECG: ECMWF delay generation

RMP: map to a common grid

MRG: merge delay images
OSCAR Web Services

All OSCAR services are ReSTful web services.

Each service consists of
• Service front-end, commonly shared among services, and
• Algorithmic back-end, which does data processing work.

The common service front-end is implemented as a python WSGI application for Apache httpd through mod_wsgi.

A service back-end can be
• Directly callable python module
• External application, such as shell scripts.

The common service front-end knows how to invoke the back-end in both cases, as long as the back-end has clearly defined call methods or stdin, stdout and stderr streams suitable for inter-process communication (ipc).
Conclusions

1. Online delay map generation using quality-controlled MODIS near-IR product
2. Online delay map generation using de-biased and topographically corrected ECMWF data
3. Weighted merging of MODIS and ECMWF delay maps
4. Clients available as workflow scripts, MATLAB modules and through web interface (www.oscar.jpl.nasa.gov)
5. Infusion path defined into ISCE (successor of ROI_pac)
Team

Eric Fielding
• Connection with InSAR community and NASA missions (DesDynI, UAVSAR)
• Applications to earthquakes and tectonics

Evan Fishbein
• Numerical weather forecast data and correction algorithms
• Merging near-IR and NWF data

Zhenhong Li
• Near-IR data and delay algorithm

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• Software architecture and implementation

Lei Pan
• Software implementation and performance improvement

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