Variability of wet troposphere delays over inland reservoirs as simulated by high-resolution WRF

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H33F-0902

MOTIVATION

The presence of water vapor in the atmosphere delays the return of radar waves in e.g. the sensing of water surface topography via satellite altimeters. Over land this typically is corrected using atmospheric conditions taken from relatively coarse spatial resolution weather forecasting models.

The questions we address here are:

- How does the wet troposphere delay (WTD) vary over inland water bodies?
- Does this differ from over neighboring land?
- What are the implications of WTD for satellite-based measurements of storage change?

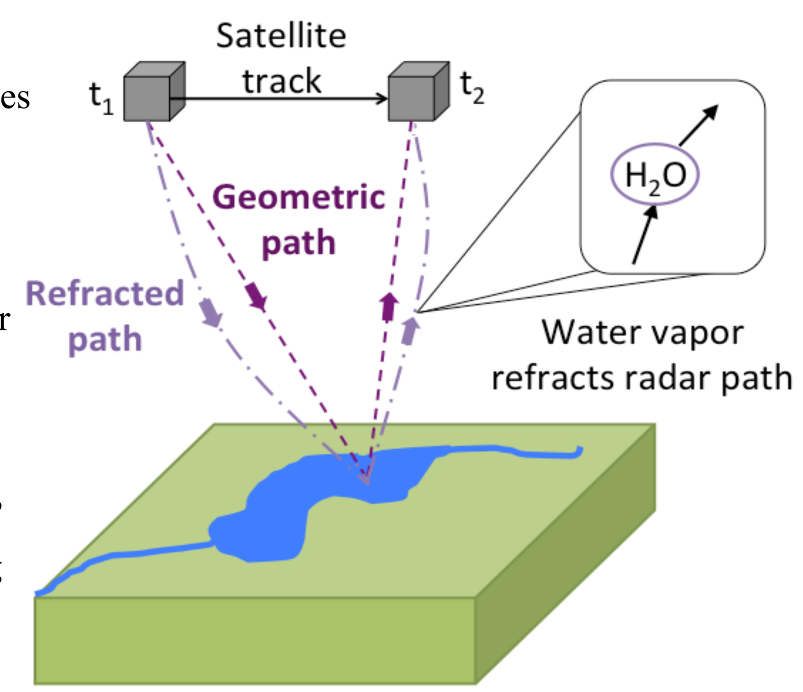


Fig. 1. Water vapor delays radar path.

METHODS

① Simulate atmospheric conditions using that ARW version of the Weather Research and Forecasting (WRF) model in Pacific Northwest (PNW) at 4-km resolution (UW PNW forecast archive, Fig. 2a) and southwestern U.S. (SW) at 2.33-km resolution (this study; Fig. 2b).

② Compute WTD from WRF simulations (Box 1).

③ Composite mean WTD over land in WRF and over water in WRF within 0.75.˚ box surrounding each reservoir.

④ Corrupt observed "True" water levels with WTD errors.

⑤ Calculate storage based on WTD-corrupted water levels (Box 2).

⑥ Compare WTD-corrupted storage relative to minimum observed "true" storage in study period.

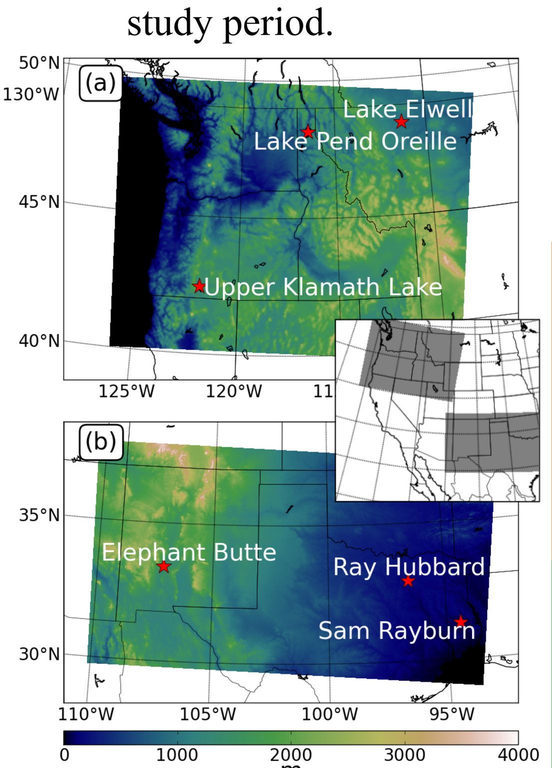


Fig. 2. WRF terrain map showing location of reservoirs.

Table 1. Reservoir properties.

Reservoir Name	River	Lake area, km^2 (volume, km^3)	Annual P, Avg. T	Main use	% of 0.75˚ box defined as water
Lake Elwell	Marias River	70 (1.8)	410 mm, 5˚C	irrig.	1.9%
Upper Klamath Lake	Klamath River	340 (0.7)	700 mm, 6˚C	elec.	6.4%
Pend Oreille Lake	Pend Oreille River	380 (1.4)	840 mm, 3˚C	elec.	9.3%
Elephant Butte	Rio Grande	150 (2.9)	390 mm, 8˚C	flood control	2.1%
Ray Hubbard	EF Trinity River	100 (0.7)	1000 mm, 18˚C	flood control	5.0%
Sam Rayburn	Angelina River	460 (7.8)	1210 mm, 19˚C	supply	8.6%

RESULTS

Black dots show water cells. Black lines outline reservoirs from GRaND.

Fig. 3. Terrain height (m) and WRF water (blue)

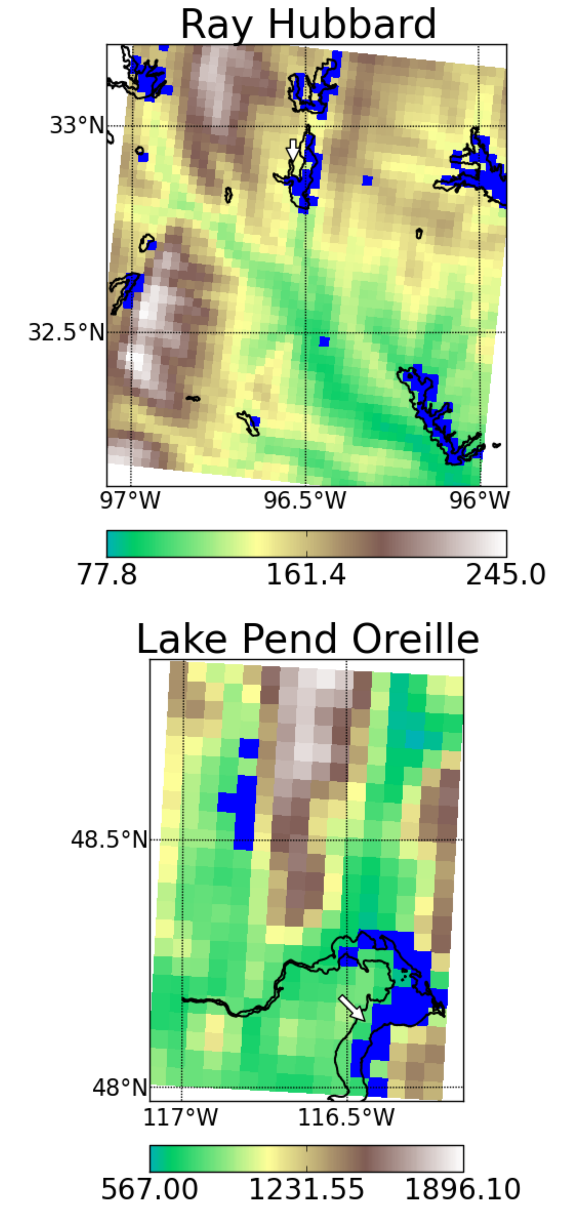
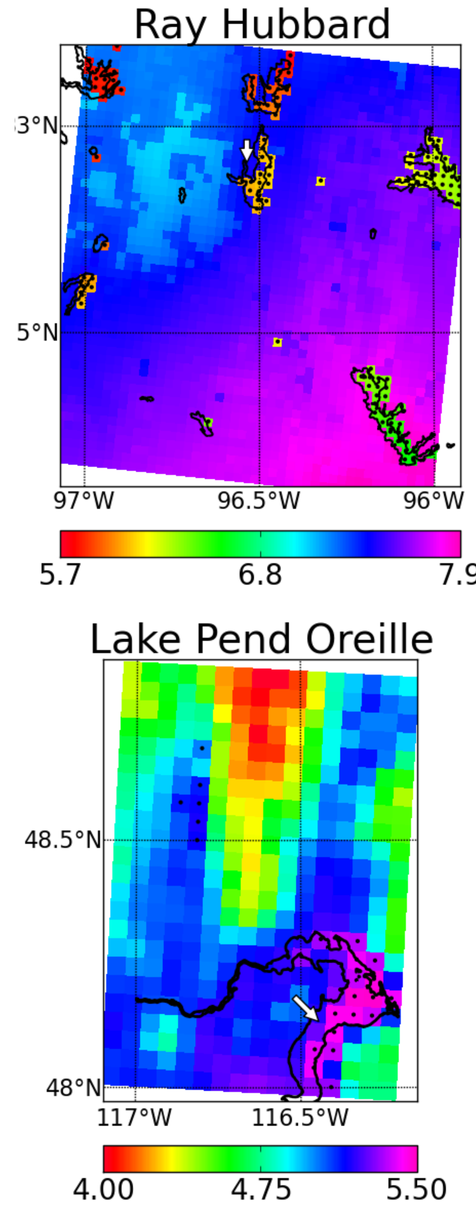


Fig. 4. Mean 2-m water vapor, g/kg

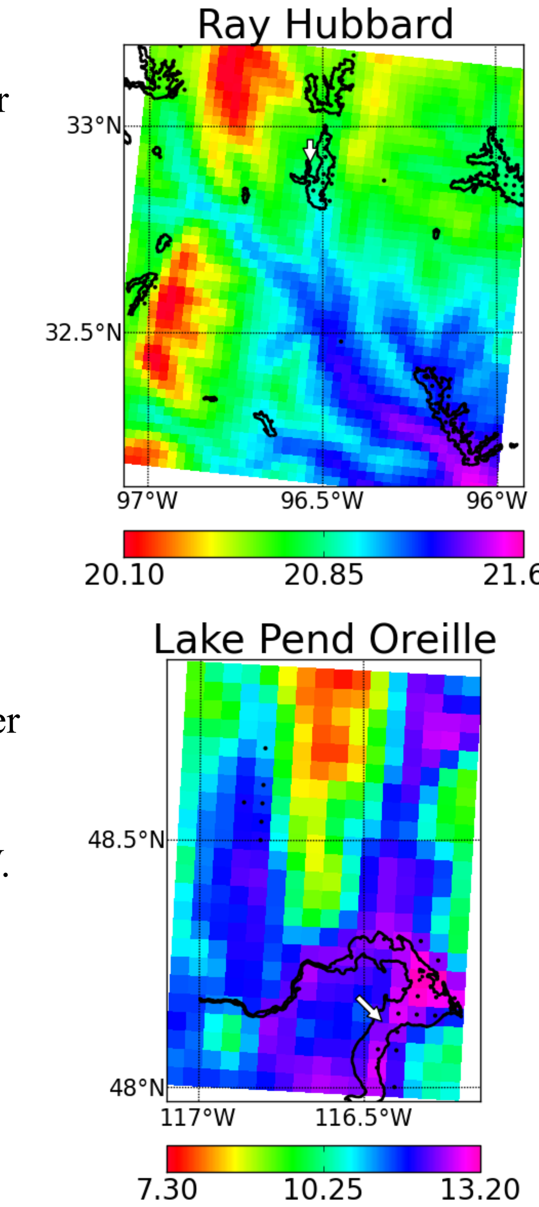


2-m water vapor is lower over water bodies than land for all Southwest sites.

2-m water vapor is higher over water bodies than land for PNW.

This effect is less distinct with small water bodies (like Lake Elwell).

Fig. 5. Mean vertically integrated water vapor, mm

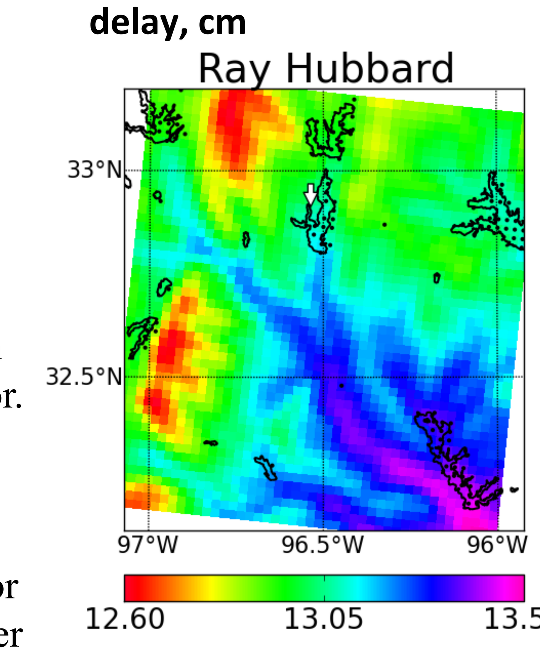


Topographic effects are more visible than water body effects in integrated water vapor.

Integrated water vapor tends to be higher over water bodies than the closest neighboring land, even in SW.

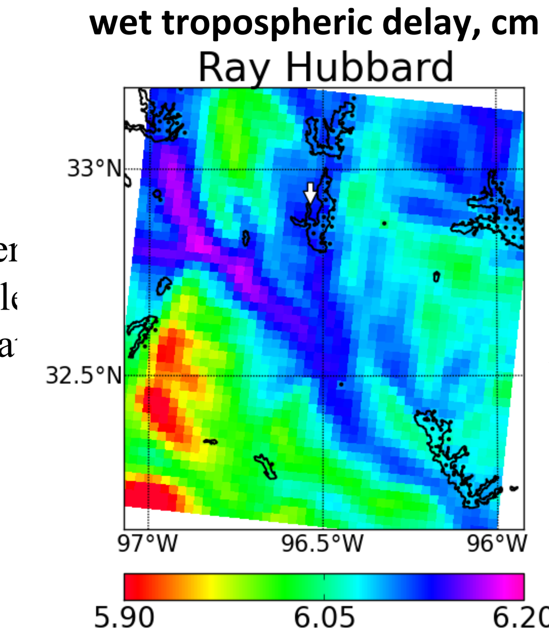
Differences over water bodies are more visible in PNW, particularly at Lake Pend Oreille.

Fig. 6. Mean wet tropospheric delay, cm

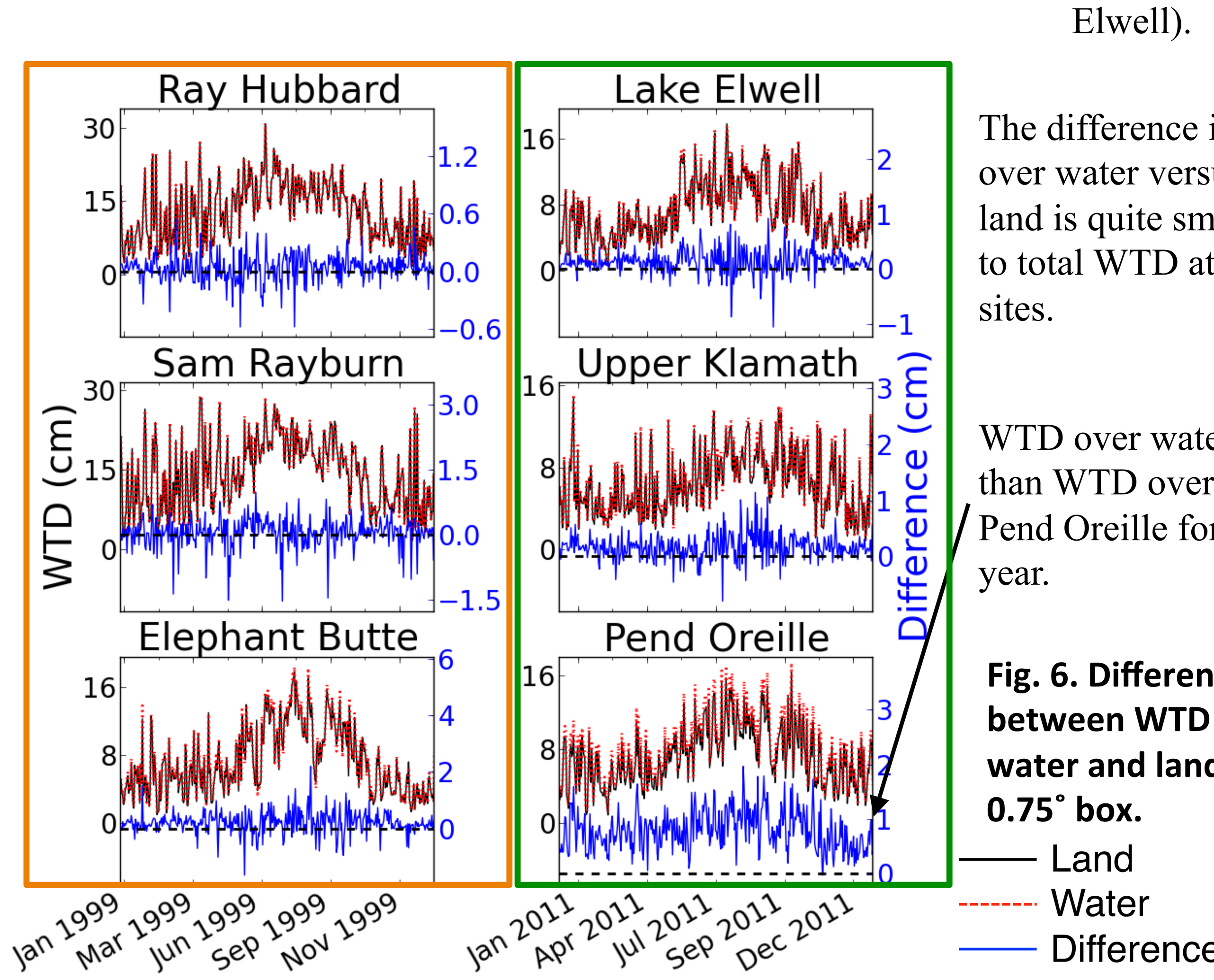


As expected, the spatial pattern of WTD follows that of integrated water vapor at all sites. The same is true for the standard deviation.

Fig. 7. Standard deviation of wet tropospheric delay, cm



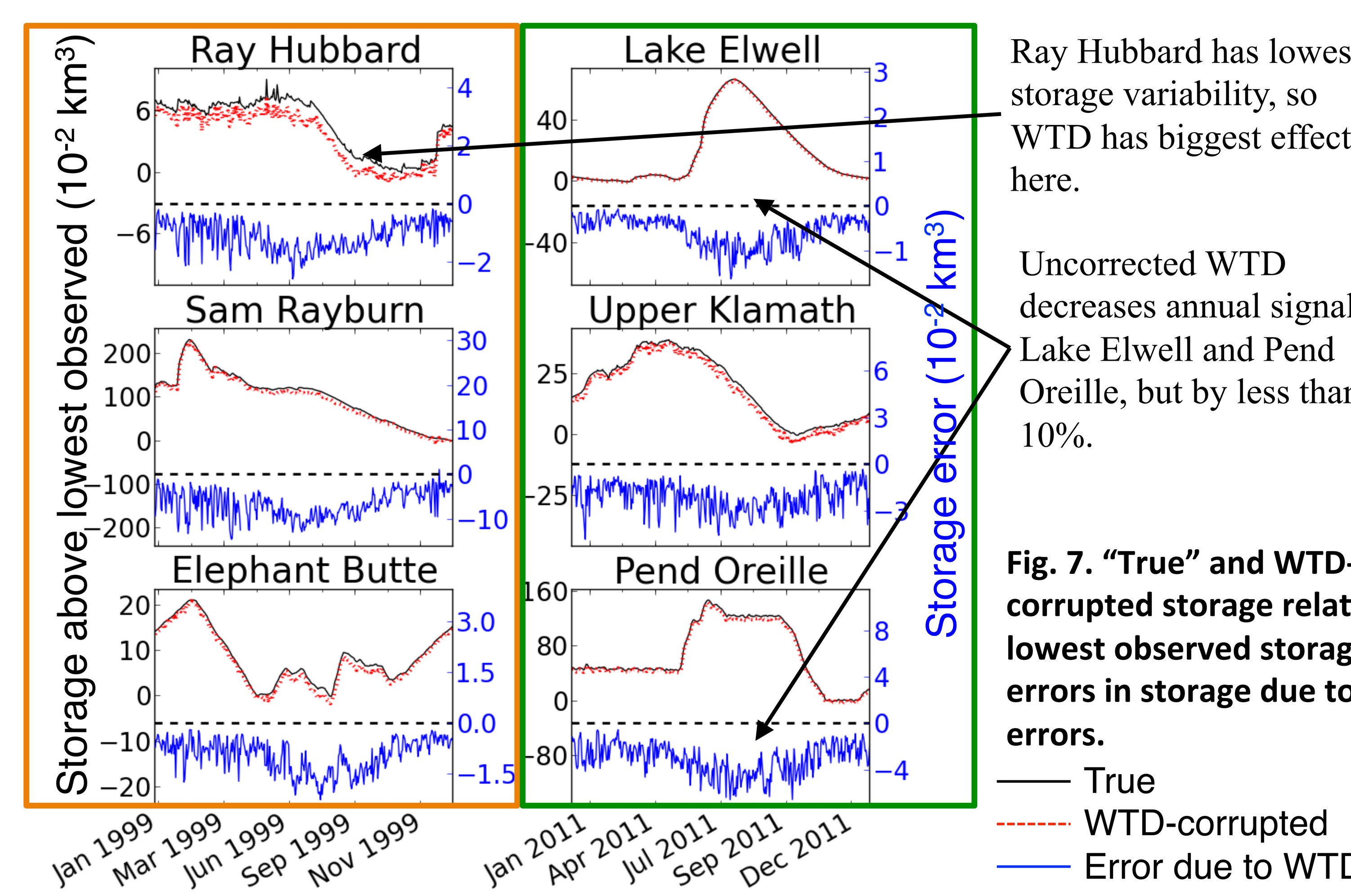
The standard deviation of WTD is higher where mean WTD is high for all sites but Ray Hubbard (shown) and Upper Klamath Lake.



The difference in WTD over water versus over land is quite small relative to total WTD at most sites.

WTD over water is higher than WTD over land at Pend Oreille for entire year.

Fig. 6. Difference between WTD over water and land within a 0.75˚ box.



Ray Hubbard has lowest storage variability, so WTD has biggest effect here.

Uncorrected WTD decreases annual signal at Lake Elwell and Pend Oreille, but by less than 10%.

Fig. 7. "True" and WTD-corrupted storage relative to lowest observed storage and errors in storage due to WTD errors.

CONCLUSIONS

- Water bodies impact water vapor near the surface, but the effects decrease with altitude.
- WTD tends to be slightly higher over water than over land in WRF at these sites (less than 10% at most times).
- WTD errors lead to lower storage estimates at all reservoirs by ~0.01-0.1 km^3, depending on the shape of the reservoir's hypsometric profile.
- WTD-corrupted storage still tracks the annual variations in reservoir storage at all sites.

Box 1: Wet troposphere delays

We compute zenith wet delay (WTD, m) from WRF output following Doin et al. (2009):

$$WTD = 10^{-6}\int_{z_0}^{\infty}\left[\left(k_2 - \frac{R_d}{R_v}k_1\right)\frac{e}{T} + k_3\frac{e}{T^2}\right]dz$$

where

R_v = specific gas constant for water vapor, 461.495 J/kg/K

R_d = specific gas constant for dry air, 287.05 J/kg/K

$k_2 = 0.716$ K/Pa; $k_3 = 3.75\times10^3$ K^2/Pa

z_0 = surface elevation, m; z = geometric elevation, m

e = water vapor pressure, Pa; T = temperature, K

Box 2: Storage from elevation

- Hypsometric curves constructed from all available "true" observations during study period.
- WTD-corrupted storage extracted from "True" hypsometric curve based on WTD-corrupted water elevation.

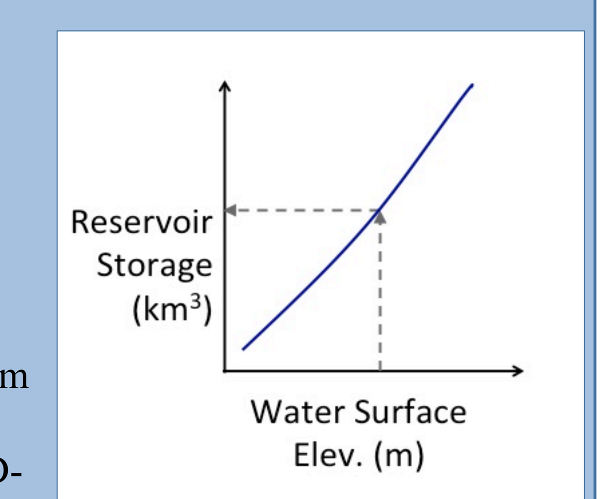


Fig. 8. Example of hypsometric curve.

Further Information

Contact Elizabeth Clark at lizaclark@ucla.edu. This work is described in more detail in Clark, E.A., D.P. Lettenmaier, 2014, Spatial variability of wet troposphere delays over inland water bodies (in prep).

REFERENCES

Doin, M.-P., et al., 2009, *J. Appl. Geophys.*, *69*, 35-50.

Lehner, B., et al., 2011. Global Reservoir and Dam Database, Version 1 (GRanDv1). doi:10.7927/H4HH6H08.

Lehner, B.,et al.. 2011. *Frontiers in Ecology and the Environment 9* (9): 494-502.

U.S.G.S. , http://waterdata.usgs.gov/nwis/.

U.S.B.R., http://www.usbr.gov/gp/ and http://www.usbr.gov/uc/.

ACKNOWLEDGMENTS

This work was funded in part by a NASA Graduate Student Education Fellowship to the first author. The authors thank Cliff Mass and David Ovens at University of Washington for access to the PNW WRF archive, and Christopher Castro, Hsin-I Chang, and Thang Luong at University of Arizona for guidance in the SW-WRF simulations. The authors also thank Konstantinos Andreadis and Ernesto Rodríguez at JPL and Delwyn Moller at Remote Sensing Solutions, Inc. for general guidance.

Post-conference addendum: The WRF simulations for SW used nearby SST as lake temperature. Because this temperature is much colder than the lakes and surrounding air in this region, 2-m water vapor is lower over water bodies than surrounding land in this region. The authors are re-running these simulations with more realistic lake temperatures.