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OTH-001

Multi-altimeter observations of the Yukon River (Alaska): Assessment of the determination of river discharge within a complex river system

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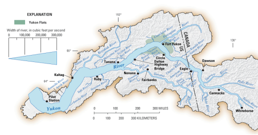
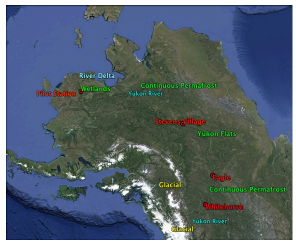
Introduction

Both radar and laser altimetry can be utilized to monitor both water level variations and channel surface gradients for the largest river systems around the world. Here, we focus on the Yukon River, Alaska. Despite it's extent and complexity, and the issues of flooding, few US and Canadian gauges exist across the basin. Both standard (Jason-2, ENVISAT) and enhanced (SARAL, CRYOSAT-2) radar altimetry, and laser altimetry (ICESat-1), offers spatially and temporally varying measurements and multiple data sets allow for cross-validations. Here, we re-examine the performance of the Jason-2 and ICESat-1 instruments with focus on tracking, acquisition, and elevation accuracy. We also discuss the merits of combining the data sets and look to their application with respect to the determination of river discharge. Applications are nationally based with basin hydrology, conservation, and hazards, as the main objectives.



River Discharge and the Yukon Basin



Understanding the Hydrology and Hydraulics of River Basins with sparse gauge networks.

• Knowledge of river discharge (the volume flow rate through a river cross section) is important for examining flow hydraulics and mass water balance across inland water basins. In addition, water resources management, measurements of riverine transport of sediment and pollution, and natural hazards evaluation, all require the monitoring and forecast of discharge information.

• River basins near the Arctic are remote thus inhibiting gauge deployment and regular maintenance. Vast wetland and floodplain complexes are also poorly gauged hampering a more thorough understanding of their hydrological complexity. Hydrological models have good spatial resolution and coverage but are limited by the accuracy of the input datasets.

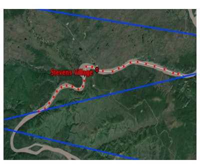
• With limitations and differing resolutions, satellite-based instruments can measure various river reach parameters, but do not have the ability to measure river discharge directly. With additional *in situ* or modeled data, and hydraulic assumptions pertaining to the river reach, the remotely sensed parameters can be translated into discharge for a variety of research and operational programs.

•The Yukon River is a major watercourse of North America. It has a drainage area of ~830,000km^2 and with an average flow of 6,430m^3/s it is one of the largest rivers discharging into the Arctic waters. The headwater lakes and streams are located in northern British Columbia but the majority of the ~3,700km long river lies in the U.S. state of Alaska and the Canadian Yukon Territory. Along its journey, the river's watershed includes many differing ecosystems; from regions of ephemeral mountain streams to mini deserts, from glacial runoff zones to forested creeks, and from areas of torrential running waters to calm wetland flats containing many small lakes and ponds.

• The Yukon has 8 major tributaries, some fed via precipitation, others via glacial, snow, or permafrost melt. Apart from the river delta region, the basin lies in a continental climate zone with large temperature extremes. Evapotranspiration is low and annual runoff is a high fraction of the precipitation. *The strong influence of temperature on runoff means that climate change is an important factor regarding variations in the river's seasonal dynamics and ecosystems*.

• There are only 4 USGS gauging stations within the US Yukon Basin and yet the basin encompasses many different climate zones and is variable in its hydrological complexity.. Satellite Radar and Laser Altimetry can help supplement the sparse gauge network.

Laser, Radar, and Enhanced Radar Altimetry

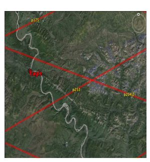


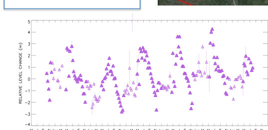
Google Earth: for channel crossing identification and thalweg distance estimation between pairs of altimeter tracks.

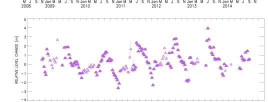
Jason-2/OSTM: for river reach water-level variability during 2008-2015, and for reach surface water gradient determination. Here, GDR-D with the Ice retracker Range is employed, and data filtering is variable according to site location.

Jason-2/OSTM Time series of river channel water-level variations (GDR) for satellite overpasses up- and down- stream of the Eagle gauge station.

OSTM Pass204
Narrowest extent 0.7km
OSTM Pass251
Narrowest extent 0.9km+island
Data losses ~10%





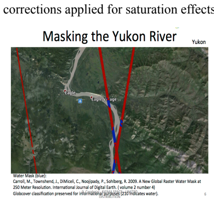


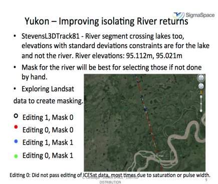
ICESat-1: for river reach surface water gradient determination.

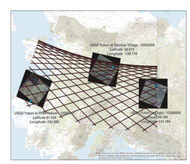
Data Editing: Received pulse width > 0.5m, but ≤ 5m, Saturation Index <9, Number of Peaks in the Waveform ≤ 2, off-nadir angle <1 degree, Maximim Smoothed waveform Amplitude ≥ 0.05, cloud flags not available for all regions and not reliable so used elevation models, elevations must be within 50m of SRTM, or within 300m of GTOPO30 AND additional use of pulse width, smoothed amplitude and number of peaks, standard deviation of elevations to be within 0.5m.

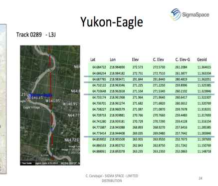
Data Masking: Use of Global Water Masks from ENVISAT, MOD44C, Globcover (300m) EQ210 and Caroll et al. (2009). Yukon region complexities also demand manual observation of satellite ground tracks in Google Earth Imagery.

Elevation Corrections: elevations are wrt T/P ellipsoid, recovered from waveform centroid as per GLA14 products. Additional corrections applied for saturation effects

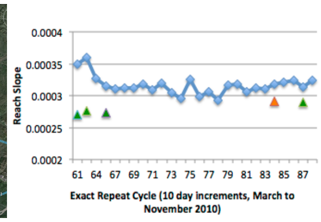




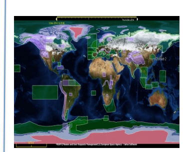


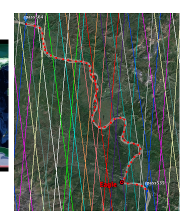


DETERMINATION OF SURFACE SLOPE: for a Yukon River reach centered on the USGS Eagle gauging station. Estimates are derived using laser altimetry (ICESat-1, satellite pass pair 178&289, and pass pair 178&1279), and radar altimetry (Jason-2, satellite pass pair 204&251). Google Earth shows positioning of ICESat1 (green) and Jason (blue) ground tracks (left). Slope estimates in blue (center, and accurate to ~5%) are from Jason-2 during the rising and falling water levels in 2010 (thalweg distance=33.5km). Multi-year (2003, 2006-2008) estimates from ICESat-1 in green and orange (thalweg distances 76.4km and 124 km respectively) (from Birkett and Carabajal, personnel communication 2015).



FUTURE PLANS: (Left) The current CryoSat-2 operating mode mask showing regions of SAR (green) and SARIn (purple) mode for enhanced surface elevation acquisitions. Low Resolution Mode (LRM, i.e., conventional radar altimetry) is in operation over the remaining ocean and land regions. Google image (right) shows the density of CryoSat-2 ground tracks over the Yukon River Eagle Station reach. Reaches can be selected with less then 1-week temporal separation between satellite overpasses or ground track pairs (e.g. pass pair 535&564 in dark blue, with 85km thalweg distance along the reach in red).

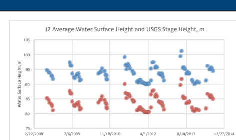


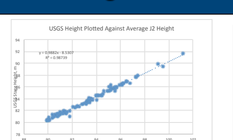


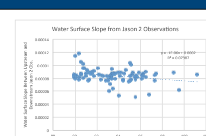
Validation and Estimation of River Discharge

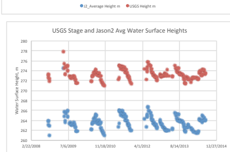
STEVENS VILLAGE: Jason-2 8/9/2008-8/1/2014 elevations deduced at sites 3+4 on pass 227 (41km apart, following the thalweg). These offer near co-incident up/downstream measurements. SIte3+4 average elevation is used for gauge validation showing same dynamic variation with 27cm rms and R^2=0.98. USGS elevations are based on the NAVD88 datum, noting data absent during winter months. USGS field slope estimates (Clement, 1999) in the vicinity of Stevens Village are in the range 1-32cm/km with an average of 14cm/km. Average Jason-2 slope=8.4cm/km is well within the expected range. Is the slope at its greatest when the levels are lowest?

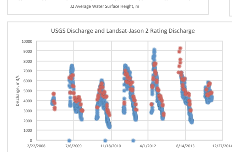
EAGLE: Time/Distance separation between passes 204 and 251, 3days/36km. Altimetric elevations are interpolated to derive slope estimates, and averaged for gauge validation (rms 67cm). USGS/Clement reports the reach slope near Eagle to be in the range 0.00001 to 0.0005 with an average of ~0.0003. Topographic map suggest slope values of 0.00036. Jason-2 slope is ~0.000335 well within expectations.











Based on a priori knowledge of mean river flow and additional Landsat-derived river channel width and meander length, a series of discharge estimates were made using a flow resistance equation (Bjerklie, 2007; Bjerklie et al., 2005, 2006). These estimates were related to the average Jason-2 elevations to define a stage-discharge rating curve. Jason-2 related discharge can then be compared to USGS discharge.

Bjerklie, D.M. 2007. "Estimating the bankfull velocity and discharge for rivers using remotely sensed river morphology information", Journal of Hydrology 341: 144-155. Bjerklie, D.M., S.L. Dingman, and C.H. Bolster, 2005. "Comparison of constitutive flow resistance equations based on the Manning and Chezy equations applied to natural rivers", Water Resources Research, vol. 41 W11502.Bjerklie, D.M., D. Moller, L.C. Smith and S.L. Dingman, 2005. "Estimating discharge in rivers using remotely sensed hydraulic information", Journal of Hydrology, vol. 309 pp. 191-209. Clement, David T., 1999, Fluvial Geomorphology of the Yukon River, Yukon Flats, Alaska, A Thesis submitted to the faculty of graduate studies in partial fulfillment of the requirements for the degree of Master of Science, Department of Geography, University of Calgary, Calgary, Alberta 199 pp. Dingman, S.L. and D.M. Bjerklie, 2006. "Hydrological Application of Remote Sensing: Surface Fluxes and other Derived Variables-River Discharge", Encyclopedia of Hydrological Sciences. John Wiley and Sons.