Coastal Applications of Altimetry:
Ted Strub, Martin Saraceno, Mike Kosro, Corinne James
CIOSS/COAS/OSU
Laury Miller, Remko Scharroo, John Lillibridge
NESDIS/SOCD

Four Altimeters
Autumn 2002 – Autumn 2005

Topex-2 (black) : 10 day repeat
Jason-1 (red) : 10 day repeat
GFO (green) : 17 day repeat
Envisat (blue) : 35 day repeat
Altimeter Measurements of Sea Surface Height (SSH)

This is the height we want to start with.
This is the height we really want.

\[ h = H - R \]

\[ = H - \left( \hat{R} - \sum_j \Delta R_j \right) \]

\( R = \hat{R} - \sum_j \Delta R_j \) is the range between the satellite and the sea surface.

\( R = \frac{c_0 t}{2} \) is the range computed from the altimeter measurements of the 2-way travel time \( t \) of radar pulses neglecting refraction, i.e., based on the free-space speed of light \( c_0 \).

\( \Delta R_j \) = Corrections for the various components of atmospheric refraction (dry gases, water vapor, cloud liquid water and ionospheric electrons) and for biases between the mean electromagnetic scattering surface and mean sea level at the air-sea interface.

\( H \) = The height of the satellite above a reference ellipsoid approximation of the Earth's surface, determined from ground-based tracking and GPS.

\( h \) = The height of the sea surface relative to the reference ellipsoid.

\[ h_d = h - h_g - h_T - h_a \]

\[ = H - \left( \hat{R} - \sum_j \Delta R_j \right) - h_g - h_T - h_a \]

\( h_d \) = The dynamic sea surface height from the effects of geostrophic currents.

\( h_g \) = Undulations of the equipotential about the ellipsoidal approximation of the Earth's surface (the marine geoid).

\( h_T \) = Tidal variations of the sea surface height.

\( h_a \) = The sea surface response to atmospheric pressure loading (the "inverted barometer effect").
Altimeter Footprint Size

Because of the details of onboard tracking of altimeter estimates of the range to mean sea level, the effective footprint size of the measurements is somewhat complicated. The instantaneous footprint diameter ranges from about 2 to 10 km:

- the footprint size increases with increasing orbit height, resulting in about 20% larger footprints at the 1336-km orbit height of TOPEX compared with the 785-km orbit height of the ERS altimeters.

- the footprint size increases with increasing significant wave height $H_{1/3}$ defined to be 4 times the standard deviation of the wave height.

In the 1-sec averages generally used in oceanographic applications of altimeter data, the along-track motion of the satellite elongates the instantaneous footprint by about 6 km.

Altimeter footprints therefore have dimensions of approximately:

- $2.5 \times 8.5$ km for a flat sea surface
- $7.5 \times 13.5$ km for $H_{1/3} = 10$ m.

**FIGURE 22** The cross-track (thin lines) and along-track (thick lines) footprint dimensions defined by the width of the middle gate $S_{med}(m)$ as a function of significant wave height for 1-sec averages of the range measurements from altimeters at orbit heights of 1336 km (solid lines) and 785 km (dashed lines). Discontinuities of the slopes of each curve occur at the transitions from one gate index to the next.

**FIGURE 23** The oval footprint characteristics defined by the width of the middle gate $S_{med}(m)$ for significant wave heights of $H_{1/3} = 1, 5,$ and 10 m for 1-sec averages of altimeter measurements of nadir mean sea level from orbit heights of 1336 km (solid lines) and 785 km (dashed lines).
Proximity to the Coastline

- **1 Hz averaged data (red)**
  - 7 km spacing too coarse?
  - Data gaps due to editing or radiometer contamination
  - ~75% of the data are flagged as bad within 30-40km of the coast.

- **10 Hz high-rate data (black)**
  - 700 m spacing - sufficient?
  - Careful near shore editing
  - Agility of altimeter acquiring sea surface after land/sea transition
  - Waveform retracking
  - Can we use the high-rate data? (Not at present)
Jason-1 Pass 28, Cycle 130: July 18, 2005

Left: Black = 20-Hz Jason data  
Red = Standard 1-Hz Jason data  
Dashed line shows radiometer cutoff; Dotted line shows coast location

Right: Black = filtered 20-Hz Jason data  
Red = Standard 1-Hz Jason data
Extending the Altimeter Alongtrack SSH to the Coast:
White lines show the extent of Standard 1-Hz Data; Black lines the extent of filtered 20-Hz data and the ECMWF model wet tropo correction.

Color is SST (red=warm, blue=cool); Signal of 20-30 cm when then altimeter crosses the upwelling jet and dense upwelled water. Within 20-50 km of the coast.
SSH signals at tide gauges have long alongshore “decorrelation” scales.
Interpolate between tide gauges to create a continuous coastal SSH signal.
ADCP Alongtrack Currents (black)
ALT+TG Currents (red)
AVISO Standard Currents (purple)

Correlations of $r = 0.73$-$0.83$
RMS differences = $11.6$-$12.6$ cm/s

Underestimates strength of summer jet over the shelf.

Adding an Ekman component at 10m makes little difference (Ekman depth = 15m)
ADCP Alongtrack Currents (black); HF Radar (red); ALT+TG+Ekman (blue dashed)

HF Radar vs ALT+TG+Ekman: $r = 0.93$; RMS = 6-9 cm/s (with seasonal cycle)

Adding Ekman components does improve the estimated of the surface current.
Future Work

Bring together those actually working on the problem, European and U.S.

• Refined radiometer wet tropo. correction? Yes. Better models needed.

• Improvements in other correction terms? Needs study, yes.

• Orbit error estimation prior to multi-satellite assimilation. Yes.

• Waveform retracking tailored to land/sea transition? Needs study.

• Hi-Rate 10 or 20 Hz RADS database for coastal altimetry? Not now.

• Regional/Coastal tide models melded with global model? Not off OR.
Net Result: >75% of data are flagged as unreliable within 40km of the coast.

Two Approaches

• Use alternatives to the standard corrections – model water vapor fields
• Use tide gauge SSH to interpolate over the 40km band of missing data
Radiometer Wet Troposphere Correction

- Radiometer footprint of ~50 km > radar’s
- Land contamination increases radiometer wet correction
- Workarounds:
  - Use model wet
  - Extrapolate to coast with Δwet constant
  - Coastal met. model?
Coastal Tides

- Largest errors in global models on shelf
- Small scale variability
- Non-linear tides: M4 and other species
- Need regional tide models embedded in open-ocean model

courtesy C. K. Shum