Several approaches to conduct quality assurance and quality control on the HFR radial velocity maps

Sung Yong Kim
Division of Ocean Systems Engineering
School of Mechanical, Aerospace & Systems Engineering
Korea Advanced Institute of Science and Technology (KAIST)
syongkim@kaist.ac.kr

Collaborators: S. H. Lee (Kunsan Nat’l Univ., Korea), KHOA, E. Terrill (SIO).
Outline

• QAQC of HF radar radial velocity maps (hindcast mode)
  • Spatial coverage of long term data
  • Correlation/covariance of pairs of radial velocities (RMS estimates)
  • 1 degree- vs 5 degree-azimuthal resolution?
  • RMS of difference of radial velocities (ideal vs. measured; CODAR only)\\
    $||r_{\text{ideal}} - r_{\text{measured}}||$
  • Geophysical signals
    • Energy spectra – tides, wind, inertial, and low-frequency forcing
    • Comparison with independent observations
  • Spatial coherence (correlation in a specific frequency band)

• Summary
Radial velocity maps (Yeosu, Korea)

- 25MHz x 2; 42MHz x 2 (Yeosu, Korea)
- About two years hourly data
Spatial coverage of radial velocity maps (Yeosu, Korea)

- Long-term data coverage can provide the spatial consistency and influence/interference of coastline.
Correlation coefficients of pairs of radial velocities

\[ r_1(t) = g_1^T u_1(t) + \epsilon_1(t) = u_1(t) \cos \theta_1 + v_1(t) \sin \theta_1 + \epsilon_1(t), \]

\[ r_2(t) = g_2^T u_2(t) + \epsilon_2(t) = u_2(t) \cos \theta_2 + v_2(t) \sin \theta_2 + \epsilon_2(t), \]

\[
\langle r_1 r_2^T \rangle = g_1^T \langle u_1 u_2^T \rangle g_2 = [\cos \theta_1 \quad \sin \theta_1] \langle u_1 u_2^T \rangle \begin{bmatrix} \cos \theta_2 \\ \sin \theta_2 \end{bmatrix}
\]

\[
\langle r_1 r_2^T \rangle = \sigma^2 (\cos \theta_1 \cos \theta_2 + \sin \theta_1 \sin \theta_2) = \sigma^2 \cos(\theta_1 - \theta_2).
\]

\[
\rho(r_1, r_2) = \frac{\langle r_1 r_2^T \rangle}{\sqrt{\langle r_1^2 \rangle} \sqrt{\langle r_2^2 \rangle}} = \frac{\sigma^2}{\sigma^2 + \gamma^2} \cos(\theta_1 - \theta_2),
\]

where \( \langle r_1^2 \rangle = \langle r_2^2 \rangle = \sigma^2 + \gamma^2 \) and \( \langle \epsilon_1^2 \rangle = \langle \epsilon_2^2 \rangle = \gamma^2 \).

(Kim et al, JGR-C; 2010)
Covariance of pairs of radial velocities

\[
\langle (r_1 + r_2)^2 \rangle = \langle u^2 \rangle (\cos \theta_1 + \cos \theta_2)^2 + \langle v^2 \rangle (\sin \theta_1 + \sin \theta_2)^2 + \langle \epsilon_1^2 \rangle + \langle \epsilon_2^2 \rangle.
\]

\[
\langle u^2 \rangle = \langle v^2 \rangle = \sigma^2 \text{ and } \langle \epsilon_1^2 \rangle = \langle \epsilon_2^2 \rangle = \gamma^2,
\]

\[
\langle (r_1 + r_2)^2 \rangle = 4 \sigma^2 \cos^2 \left(\frac{\theta_1 - \theta_2}{2}\right) + 2 \gamma^2.
\]

(Kim et al., JGR-C; 2010)
1- vs. 5-degree azimuthal resolution?

Radial velocities along a single range cell

1 degree radial solutions

5-degree bin averaged radial solutions
1- vs. 5-degree azimuthal resolution?

![Graph showing spectrum with different azimuthal resolutions. The x-axis represents wavenumber [cycles per degree (cpd)], and the y-axis represents spectrum (cm²·s⁻²·cpd⁻¹). Two lines are shown: one for Δθ = 1° (black) and another for Δθ = 5° (red). The noise level is indicated by a horizontal blue line.]
RMS of difference of radial velocity maps (ideal, measured)

- Overlaid with radar beam pattern and rms of difference of radial velocities
- Anomalous radial velocities in an azimuthal direction with a sharp peak of the beam pattern
Geophysical signals: Energy spectra

Courtesy: E. Terrill and T. Cook (SIO)
CCAR/AVISO interpolated products are projected into the radial direction.

Coherent and incoherent with events; geostrophic components or potential errors.
Spatial coherence: Correlation in a specific freq. band

- Spatial coherence of radial velocities in the near-inertial frequency ($|\sigma - fc| < 0.1$ fc) and low frequency band ($\sigma < 0.2$ cpd).

- Expected O(100) km length scales for the offshore case.

$$\hat{c}(\Delta x, \hat{f}_c) = \frac{\langle \hat{u}(x, \hat{f}_c) \; \hat{u}^\dagger(x + \Delta x, \hat{f}_c) \rangle}{\sqrt{\langle |\hat{u}(x, \hat{f}_c)|^2 \rangle} \sqrt{\langle |\hat{u}(x + \Delta x, \hat{f}_c)|^2 \rangle}} ,$$
Energy spectra of radial velocities in range and freq. domains

- Wavenumber spectra in the range direction
- Approximated energy spectra in the frequency domain

\[ \tilde{\xi}_s(\sigma_s) = A\sigma_s^{-\alpha} + \sum_{n=1}^{N} B_n \exp \left( -\frac{|\sigma_s - \nu_n|}{(\lambda_t)_n} \right) , \]
Summary

• **Hindcast mode QAQC** of HF radar radial velocities using statistics and geophysical consistency using long-term observations.

• Spatial coherence and energy spectra can be a first check

• Beam pattern issues may require the long-term data and reprocessing the data.

• Correlation and covariance of pairs of radial velocities can provide the noise of radar observations, which can be used in the optimal interpolation for vector current mapping.

• For **real-time mode QAQC**, the residual of the optimal interpolation can be a criteria to discern the outliers and spurious data.