Remote Sensing:

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Active microwave systems (3)
Scatterometers, SAR and CODAR
• Scatterometers
  – satellite borne
  – ocean surface vectors winds
    • Incorporated into ECMWF meteorological analysis

• Synthetic Aperture Radar (SAR)
  – satellite and aircraft
  – high spatial resolution (tens of meters)
  – image ocean surface wave field and, by inference, processes that modulate the surface waves

• CODAR (Coastal Ocean Dynamics Application Radar)
  – land-based HF radar system
  – ocean surface currents and waves

All these systems exploit the resonant “Bragg” scattering of centimeter to decameter wavelength microwave radiation from ocean surface roughness due to short waves.
Bragg Scattering from Water Surfaces

Wind creates small waves on the ocean surface (capillary waves) which in the absence of wind quickly die out.

If wind continues, waves will grow in size and increase in wavelength and height to become ultra-gravity waves and eventually gravity waves.

A water surface affected by wind will have a spectrum of surface waves, e.g., multiple wavelengths and heights.

Microwave EM energy has been shown (in wave tank experiments) to constructively interfere or resonate with surface capillary and ultra-gravity waves.

This phenomenon is known as Bragg Scattering.
Figure 11 depicts the resonant scattering of microwaves on gravity-capillary waves, called Bragg scattering. The condition for resonance of the incoming microwaves is

$$\lambda_B = \frac{n \lambda}{2 \sin \theta}$$

(5)

where $\lambda$ and $\theta$ are the microwave wavelength and incidence angle respectively, $\lambda_B$ the gravity-capillary (Bragg) wavelength, and $n$ a positive whole number. The condition $n = 1$ contributes predominantly to the microwave return (see, e.g., Valenzuela [1978]) and one

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**Figure 11.** Bragg scattering: A plan-parallel radar beam with wavelength $\lambda$ hits the rough ocean surface at incidence angle $\theta$, where capillary gravity waves with Bragg wavelength $\lambda_B$ will cause microwave resonance.
- Development of scatterometry is largely empirical

- There is a relationship between the amount of backscattered microwave power and the energy density of the gravity-capillary waves

- Relationship between energy density and surface momentum flux, or stress $\tau$

- Empirical calibration of observed $U_{10}$ winds (m/s) vs. radar backscatter $\sigma$ has been determined

- The backscatter brightness is greatest looking directly upwind or downwind

- By taking multiple looks at the sea surface in different directions, the vector wind direction and wind speed can be inferred
Figure 12.4 The scattering cross section per unit area of the sea as a function of angle relative to the mean wind for 13.9 GHz radio signals at 40° incidence angle (from Jones and Schroeder, 1978).
Scatterometers for ocean vector winds

• Operate in microwave band
  – scatterometers observe winds through all cloud conditions

• Pioneered by SeaSat (6 months)

• Followed by NSCAT (1999: 10 months)
  – Two-sided double-swath scatterometer

• QuikSCAT (since 1999) and ADEOS II (2003: 5 months) platforms
  – SeaWinds conical scan scatterometer

• Science and operational objectives
  – all-weather, high-resolution, near-sea-surface vector wind data over the global oceans
  – atmospheric forcing, ocean response and air-sea interaction mechanisms on various spatial and temporal scales
  – weather forecasts, especially near coastlines
  – wave-prediction models
  – storm warning and monitoring
ERS Scatterometer

Resolution = 50 km

Obtains measurements looking upwind, cross-wind, and downwind

Empirical Algorithms used to estimate wind speed and direction
Figure 7. On the left, sketch of the microwave illumination pattern of a) SASS, b) NSCAT, c) SeaWinds, and d) SCAT, and, right, e) ASCAT on the earth's surface. The gray areas denote the swath and the arrow the direction of the ground track. All beams pass a particular location in the swath within ~7 minutes. The ERS SCAT has a swath only at one side of the spacecraft and has therefore a smaller area coverage than the other scatterometers shown here. See text for further explanation.

a) Ground track

500km

VV
HH

45°

315°

225°

400km

SeaSat

b) Ground track

600km

VV
HH

315°

295°

115°

330km

NSCAT

Ground track

600km

VV
HH

45°

115°

225°

225km

ERS
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Figure 12.5 If a radar observes a particular cross section $\sigma_0(\theta)$ at an azimuthal angle $\theta$ relative to the wind, all points on the curve are possible wind vectors that yield the observed cross section. If the oceanic area is observed from two different directions, $\theta$ and $\theta + 90^\circ$ in this example, up to four possible wind vectors satisfy the observations. These are the intersections of the two curves. Thus wind direction is not uniquely determined. If three observations are made, the ambiguity is reduced, but the observations must be very precise because scatter is only weakly anisotropic (from Jones et al., 1982).
SeaWinds

- 1-meter-diameter rotating dish producing 2 spot beams sweeping in a circular pattern
- 200 kg, 220 Watts power
- 1,800 km swath during each orbit provides approximately 90% coverage of oceans daily
- Wind-speed measurements of 3 m/s to 20 m/s +/- 2 m/s accuracy; direction +/- 20° accuracy
- Wind vector resolution of 50 km
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Seawinds
(QuikSCAT, ADEOS)

http://podaac.jpl.nasa.gov/ovw/
Surface Analysis without QuikSCAT

From Rick Knabb, Tropical Prediction Center
Surface Analysis with QuikSCAT
Wind speed and direction in the Pacific Ocean on August 1, 1999, gathered by the SeaWinds instrument onboard QuikScat. The intense surface winds of Typhoon Olga, represented by yellow spirals, can be seen moving around South Korea.
Wind speed and direction in the Atlantic Ocean on August 1, 1999, gathered by the SeaWinds instrument onboard QuikScat.
Synthetic Aperture Radar
• Synthetic Aperture Radars map radar reflectivity of the sea over areas 50 km to 100 km on a side, with a resolution of 10 to 40 m

• Range measurement and resolution are achieved in the same manner as most other radars

  – range is determined by precisely measuring the time from transmission of a pulse to receiving the echo from a target
  – in the simplest SAR, range resolution is determined by the transmitted pulse width, i.e. narrow pulses yield fine range resolution
• The other dimension is azimuth (or along track) and is perpendicular to range

  – SAR produces relatively fine azimuth resolution: this differentiates it from other radars

  – fine azimuth resolution requires a physically large antenna to focus the transmitted and received energy into a sharp beam

  – the sharpness of the beam defines the azimuth resolution

  – [optical systems, such as telescopes, require large apertures - mirrors or lenses are analogous to the radar antenna - to obtain fine imaging resolution]

  – even moderate SAR resolutions require an antenna physically larger than can be practically carried by an airborne or satellite platform ~ several 100 m
- SAR collects data while flying this distance and processes the data as if it came from a physically long antenna.

- The distance the aircraft or spacecraft flies in synthesizing the antenna is the synthetic aperture.

- Fine azimuth resolution is also the result of Doppler processing.

- Target position along the flight path determines the Doppler frequency of its echoes: Targets ahead produce a positive Doppler offset; targets behind produce a negative offset.

- As the spacecraft flies traversing the synthetic aperture distance, echoes are resolved into a number of Doppler frequencies to determine azimuth position.
Figure 1. Sample RADARSAT-1 SAR wind speed image crossing the Aleutian Islands with wind speed displayed in pseudo color. Note the von Kármán vortices in the lee of a volcano and gap flows caused by land topography.
Figure 13.6 Some processes influencing SAR observations of ocean waves. Large ocean waves (a) tilt the surface, and (b) interact with short waves and distort the airflow over the surface. Both processes modulate the heights of the short waves that reflect the radar signal. And (c), large waves move the surface, thus distorting the SAR image of the surface and producing wavelike patterns in the image.
Figure 2. ERS-1 SAR C-band VV image of the New York Bight taken on July 31, 1995. Image is approximately 100 km x 100 km. Four packets of tidally generated internal waves are visible north of the Hudson Canyon, which lies near the bottom center of the image. Distance between packets is set by $12 \frac{1}{2}$-h semidiurnal tidal period. ©Copyright European Space Agency, 1995
Figure 3. ERS-1 C-Band VV SAR images of the NY Bight shown with the local bathymetry. Bathymetry derived from GEBCO Digital Atlas 97.
• High-frequency (HF) radio in the band 3-50 MHz has wavelengths 10 m to 100 m

• The ocean surface is rough surface, with water waves of many different periods

• Bragg scattering occurs for narrow band of wavelengths depending on CODAR frequency

• 25 MHz transmission -> 12m EM wave -> 6 m ocean wave
  12 MHz transmission -> 25m EM wave -> 12.5 m ocean wave
  5 MHz transmission -> 60m EM wave -> 30 m ocean wave

• Radar return is greatest for waves traveling directly toward or away from the antenna

• Therefore we know wave direction and wavelength
• From surface gravity wave dispersion theory we know the wave period and hence wave speed

• Wave speed creates a Doppler frequency shift in the radar return

• In the absence of ocean currents, the Doppler frequency shift would always arrive at a known position in the frequency spectrum

• Observed Doppler-frequency shift includes the theoretical speed of the speed of the wave PLUS the influence of the underlying ocean current on the wave velocity in a radial path (away from or towards the radar)

• Once the known, theoretical wave speed is subtracted from the Doppler information, a radial velocity component of surface current is determined.

• The effective depth of the ocean current influence on these waves depends upon the wave period and wave length. The current influencing the Bragg waves falls within the upper meter of the water column.

• By looking at the same patch of water using radars located at two or more different viewing angles, the total surface current velocity vector can be resolved
Fig. 6. A typical Doppler Shift spectrum from a beam-forming radar receiver. The JCU 30 MHz COSRAD system.
A SeaSonde HF radar unit has one transmitting antenna and one receiving antenna. The transmitting antenna is omni-directional—it radiates a signal in all directions. The receive antenna unit consists of three colocated antennas, oriented with respect to each other on the x, y, and z-axes (like the sensors on a pitch and roll buoy). It is able to receive and separate returning signals in all 360 degrees.

For mapping currents, the radar needs to determine three pieces of information:

- Bearing of the scattering source (the target)
- Range of the target
- Speed of the target
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  – bearing of the scattering source (the target)
  – range of the target
  – speed of the target
The first determination is Range to target.

- The SeaSonde modulates the transmitted signal with a swept-frequency signal and demodulates this in the receiver

- the time delay is converted to a large-scale frequency shift in the echo signal

- Therefore, the first digital spectral analysis of the signal extracts the range or distance to the sea-surface scatterers, and sorts it into range bins (typically 5 km)
The second determination is Speed of the target.

- the signal is processed for ~ 4 minutes to produce an average spectrum from which the Doppler shift is calculated
- this gives speed accuracy of ~ 4 cm/s

The third determination is Bearing of target

- the receive antenna has 2 directional ‘loop’ antennas and 1 omni-directional whip antenna
- the loop antenna patterns receive power differently form the same incoming direction
- processing the signal difference from the 2 loop antennas, normalized by the omni-directional antenna, performs the direction finding
Fig. 3. Antenna patterns for the crossed loops and vertical whip antennas. The solid and dashed lines are for the vertical loop antennas and the dot-dash line is for the omni-directional whip used for calibration. The straight line in the first quadrant indicates an incoming signal.
Spatial Maps
10/16/2002 0700 GMT

RUC Wind and Pressure Analysis

CODAR Surface Currents

Contour resolution – 1 mb
10/16/2002 1800 GMT

RUC Wind and Pressure Analysis

Contour resolution – 1 mb

CODAR Surface Currents

Surface Velocity (cm/s)
10/17/2002 0000 GMT

RUC Wind and Pressure Analysis

CODAR Surface Currents

Contour resolution – 1 mb