

# Mapping Ocean Currents With IKONOS

- using the apparent velocity of ocean gravity waves

*Ron Abileah*  
*abileah@jOmegak.com*

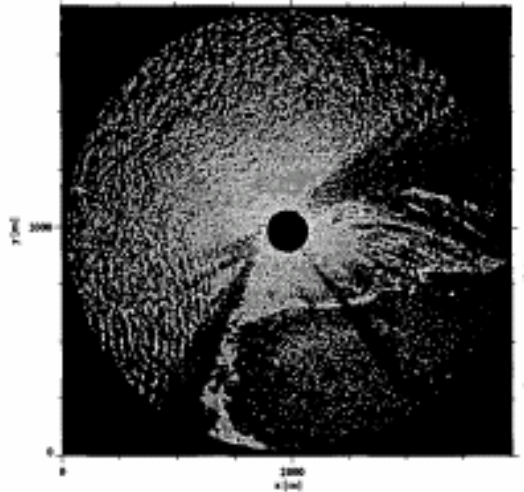
**jω(k)**

jOmegak.com

# Outline

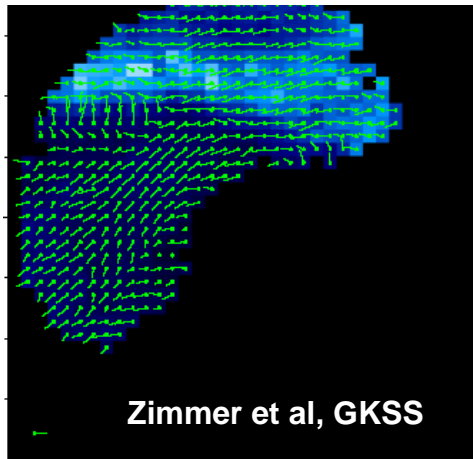
Previous work  
Theory  
Application to IKONOS  
Test case  
Results  
Error analysis  
Conclusions

# Previous work (partial list)



Using nautical X-band radars to image waves

TNO (NL)  
GKSS (Germany)  
OceanWaveS GmbH (Germany)  
SeaDarQ (NL)  
Miros (NO)

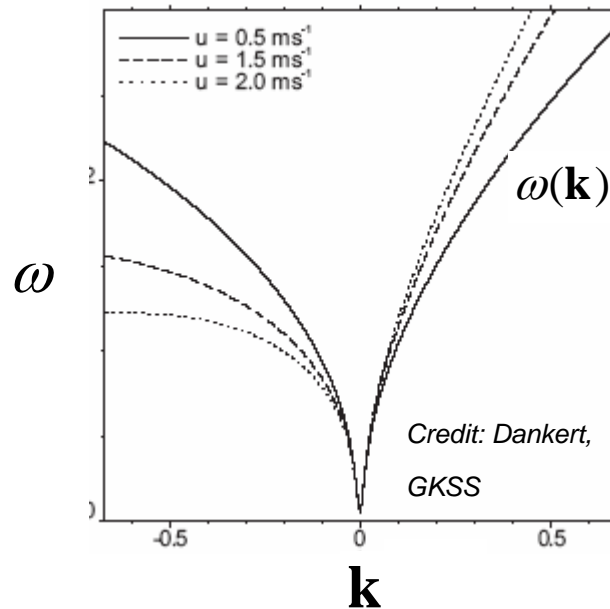


Using aerial videography

Stockdon and Holman (USA)  
Arete (USA)

# Theory

$$F(\omega, \mathbf{k}) = \frac{1}{2\pi} \int_{-\infty}^{+\infty} dx dy dt f(x, t) \exp(-i(\mathbf{k} \cdot \mathbf{x} - \omega t))$$



Ocean surface drift velocity

$$\omega(\mathbf{k}) = \omega_0(\mathbf{k}) + \mathbf{k} \cdot \mathbf{U}$$

Gravity waves

$$\omega_0(\mathbf{k}) = \sqrt{g |\mathbf{k}| \tanh(|\mathbf{k}| d)}$$

# Solution for U

Use LSQ to fit  $\omega(\mathbf{k})/U$  to the energy concentration in  $H(\omega, \mathbf{k})$

Many version have been implemented. **See references.**  
Require  $\sim 100$  images at intervals  $\Delta \sim 1$  s.

Following works well with any number of images, and any  $\Delta$ .

$$F_t(\mathbf{k}) = \frac{1}{2\pi} \int_{-\infty}^{+\infty} dx dy f_t(\mathbf{x}) \exp(-i(\mathbf{k} \cdot \mathbf{x}))$$

correlation:  $\max_n \left| \sum_k H(k) \overline{F_n(k)} F_{n+1}(k) e^{-(j\omega(|k|)+U \cdot k)\Delta} \right|$

difference:  $\min_n \sum_k \left| F_n(k) - F_{n+1}(k) e^{-(j\omega(|k|)+U \cdot k)\Delta} \right|$

# Special considerations for acquiring satellite imagery

Multiple images must be taken in one overpass, as close in time as possible

Geo-registration required to  $\frac{1}{2}$  m accuracy

Images as provided by satellite vendor are not registered to sufficient accuracy

Need land features in the image area to achieve  $\frac{1}{2}$  m

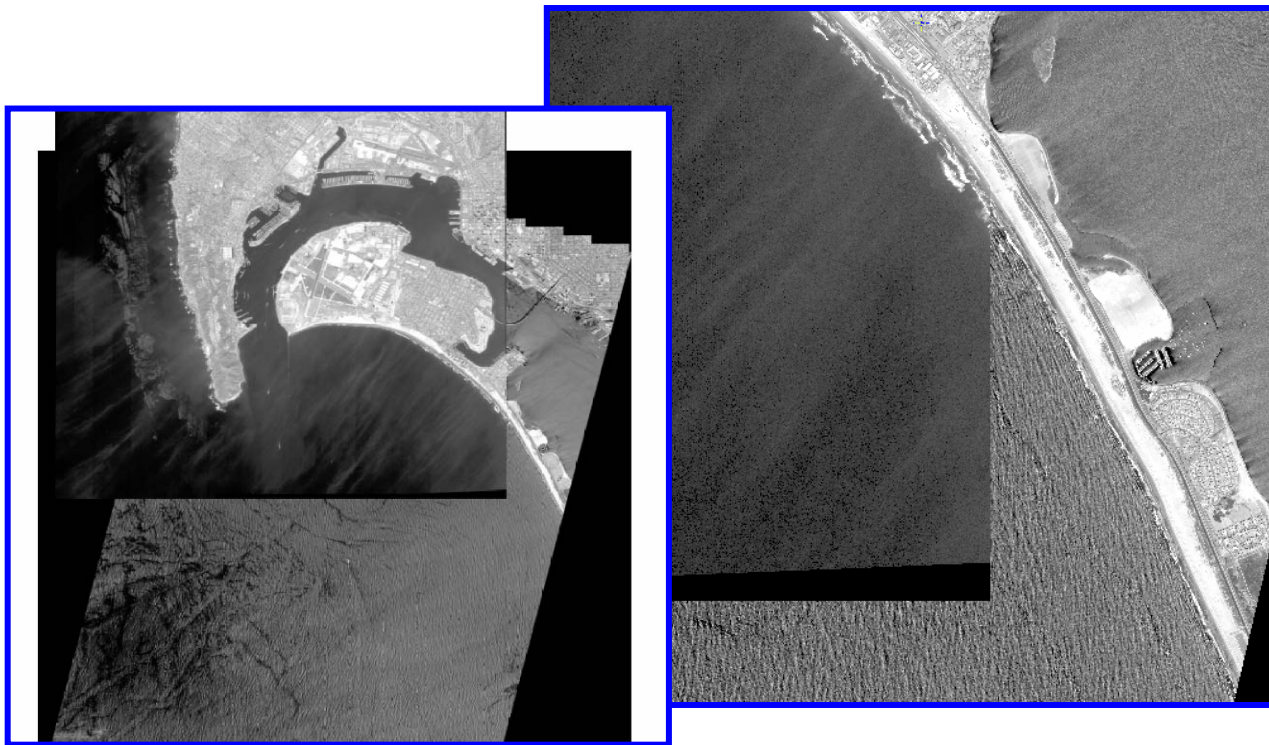
Short wind waves (4-20 m) must be present

Longer wavelength provide much less accuracy



# Special considerations for acquiring satellite imagery (continued)

Best wave visibility is  $\sim 30^\circ$  from the solar specular point



# Special considerations for algorithm

Very few images

Previous implementations used 100's to compute  $F(\omega, \mathbf{k})$

Longer time interval between images

Critical sampling of short wind waves requires 1 frame/sec,  
IKONOS intervals are 13 sec

Multi-spectral

Spectral discrimination useful to filter non-surface wave features

Push broom imager

Image time varies from top to bottom

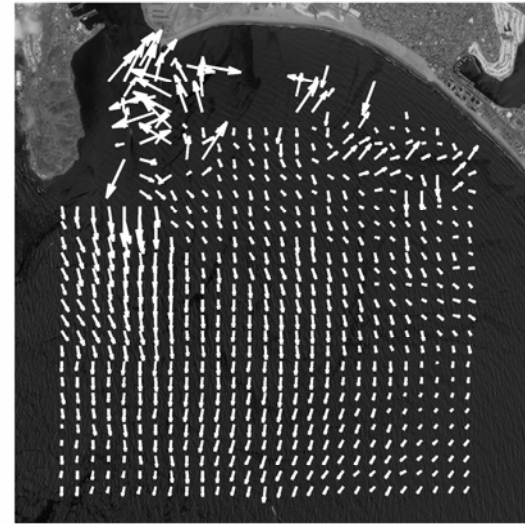
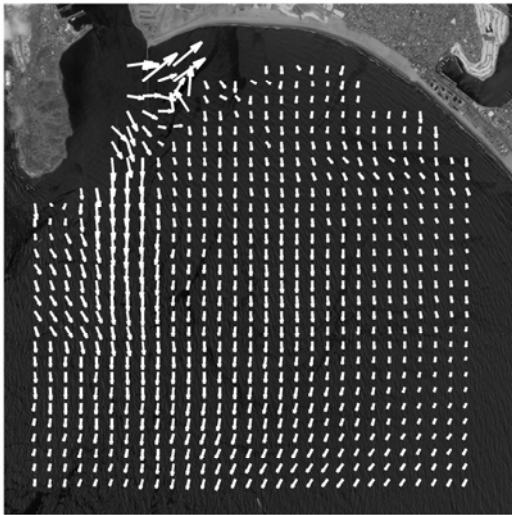
See paper for details

# Test case



full  
cropped

# Results



# Error analysis

## Best approach

Simultaneous *in situ* measurements

## Alternative

### Spatial consistency

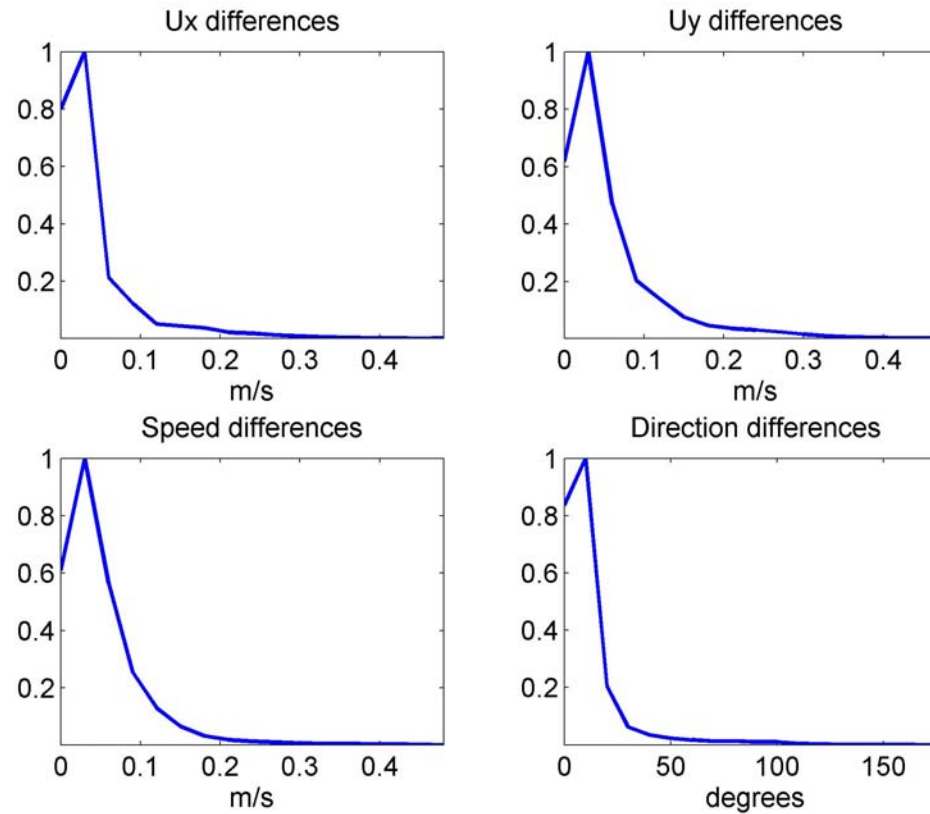
Variability on small spatial scales

### Temporal consistency

Difference between two independent image-pairs

# Spatial consistency

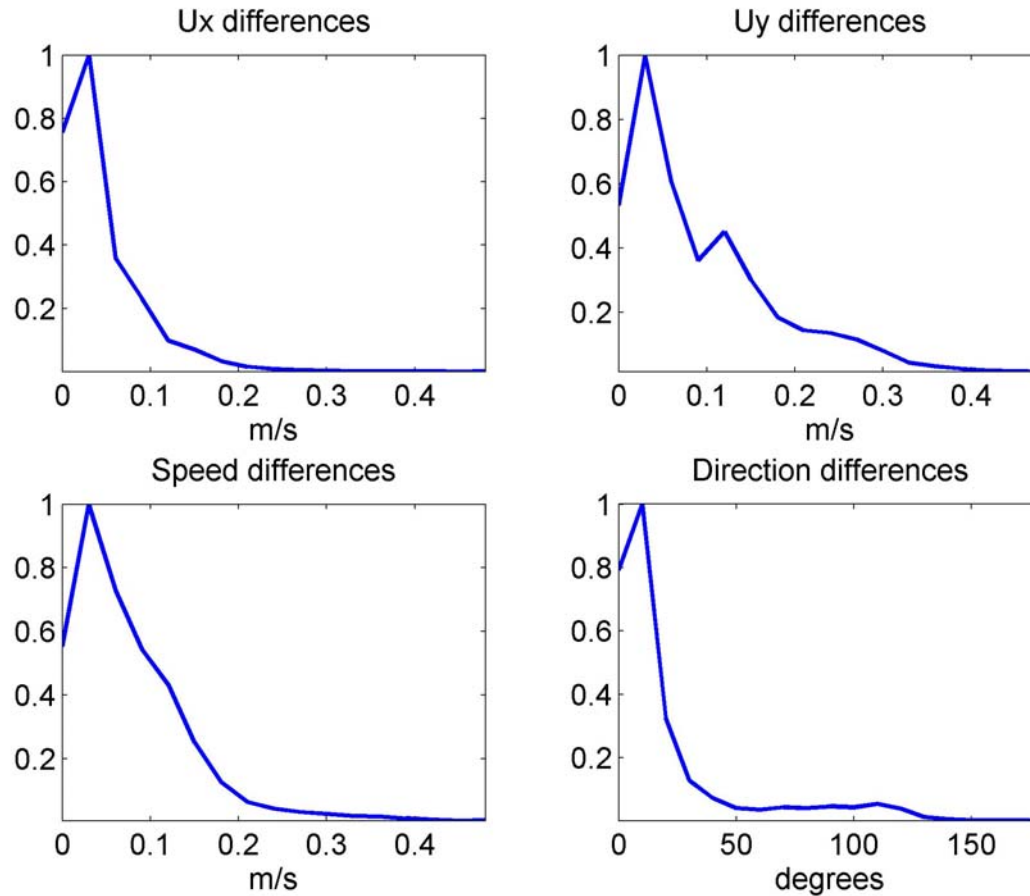
based on estimates separated by 192 m



# Image pairs for temporal consistency test

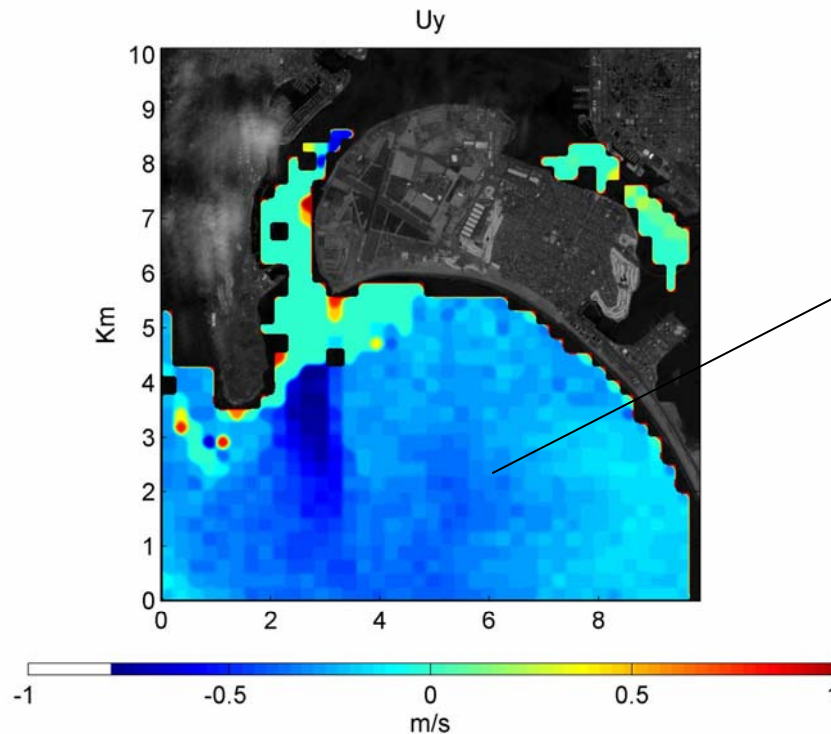
ID	Time	Collection Azimuth	Collection Elevation
178113	18:46:23.4	3.6°	56.4°
178116	18:46:36.7	0.9	62.8
178114	18:46:49.4	356.1	69.8
178117	18:47:2.7	345.3	77.0

# Temporal consistency



# Summary of rms differences

rms differences in cm/s

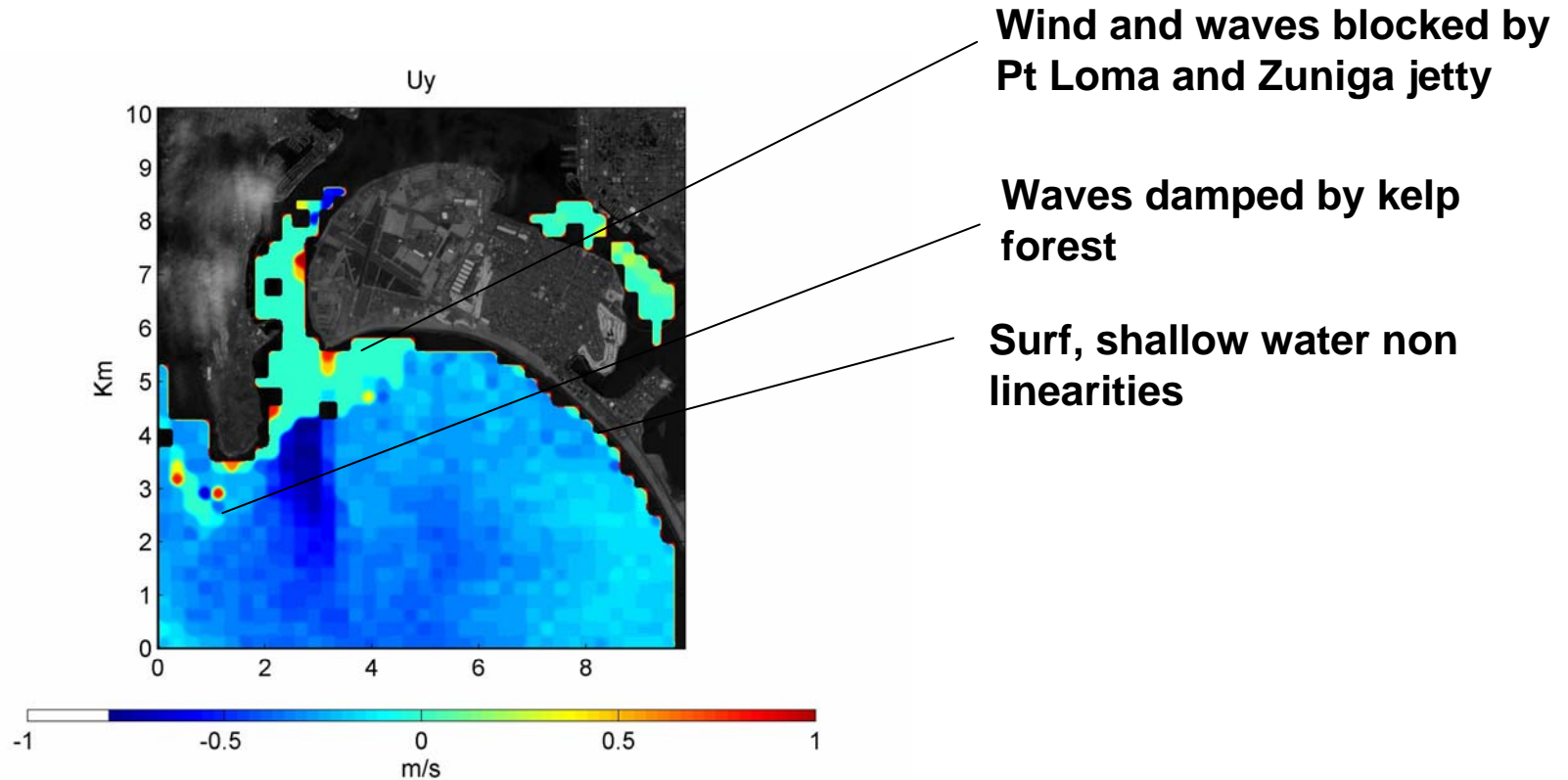


Spatial    Temporal

Ux	7	7
Uy	9	13
Speed	8	11

If rms differences are ~10 cm/s, the rms errors must be <7 cm/s

# Gaps where there are no wind waves



# Concluding comments

Demonstrated mapping ocean surface currents with IKONOS images.

Errors, based on estimating current with two images:

rms error <7cm/s

spatial resolution 100m

The rms error and resolution is comparable to previous results with marine radars and aerial videography

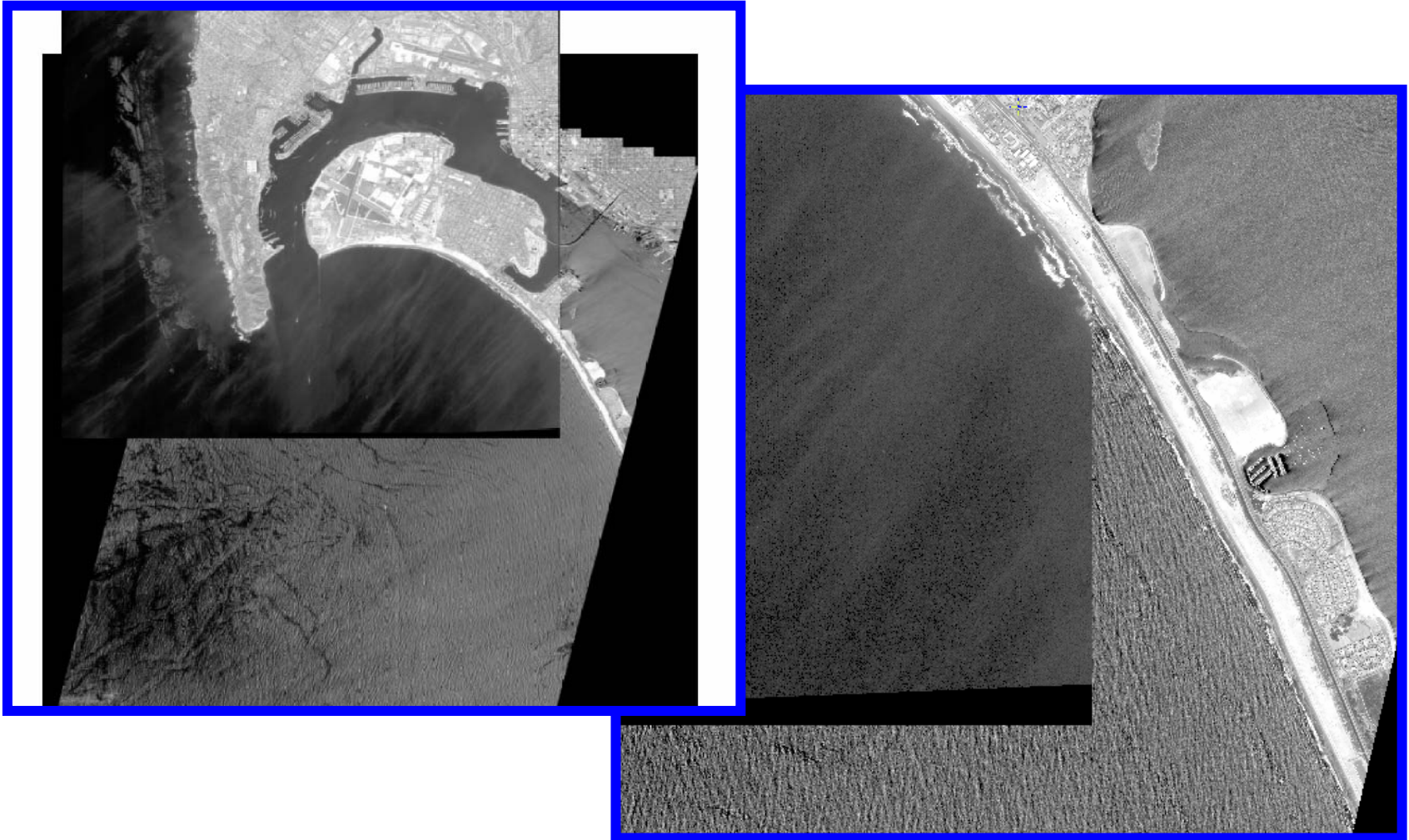
Greater accuracy and resolution possible

Combine multiple image pairs; up to 4 is practical with IKONOS

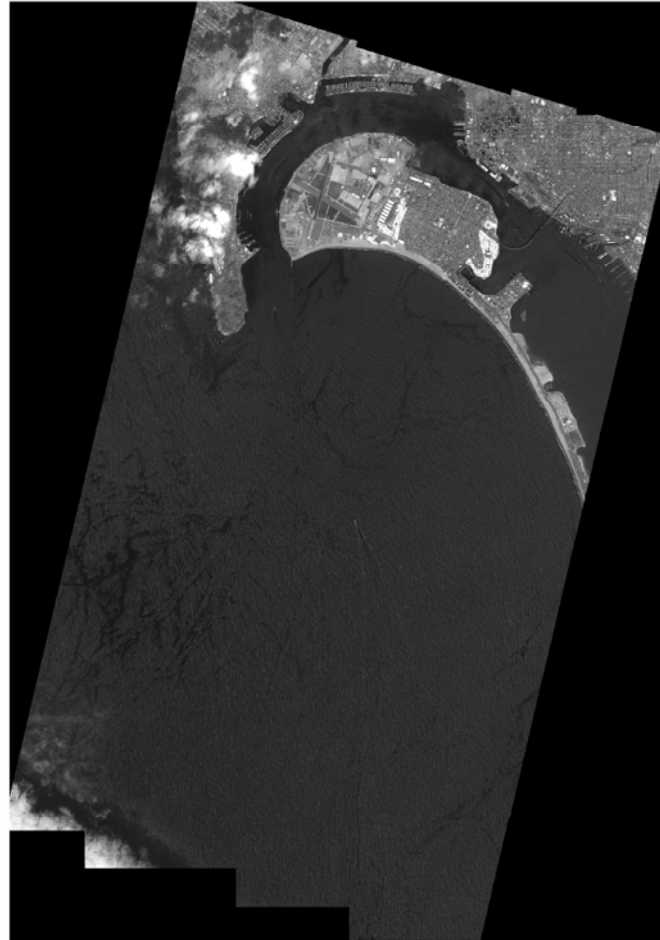
**Questions?**

# Backup Slides

# Images from March 25 and April 8, 2002



# Scan



# Beach features used for image registration

