Coastal Winds in Upwelling Regions

Scatterometry, Models and Climate Variability

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with help from
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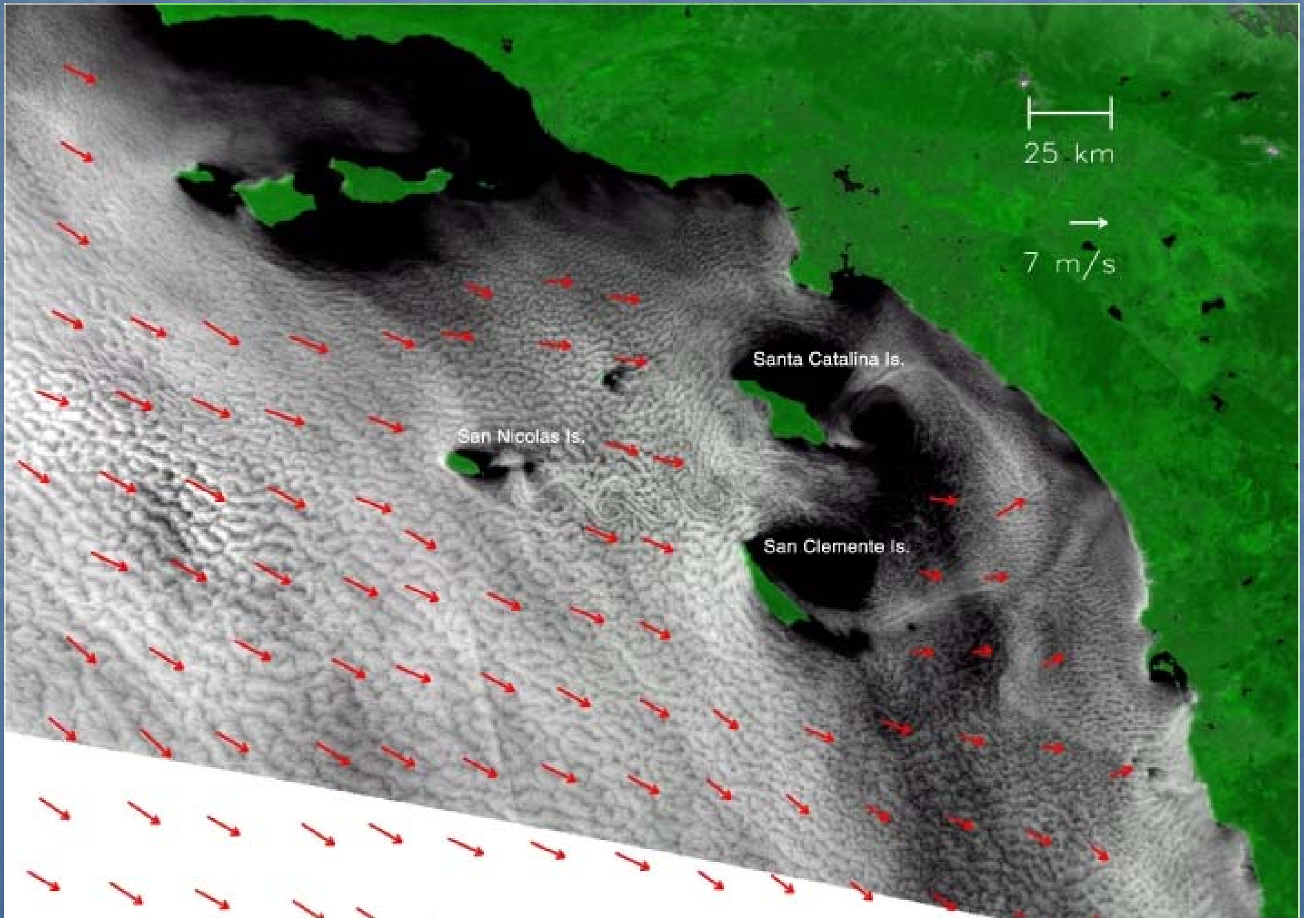


Figure:

thanks to
Mike Freilich

Coastal Winds, Climate and Scatterometry: The Message

- ***Coastal wind fields have "small-scale" structure, controlled by the geometry and other characteristics of the land-water boundary, by the strength of the alongshore winds, the height and stratification at the top of the MABL, and by gradients in ocean SST.***

Two-Dimensional Wind Fields Vary due to V, h, Δ Θ

Next to the coast, the structure of the fields depends on several parameters:

V: Upstream alongshore velocity (changes on diurnal-climate scales);

h: Height of the Marine Boundary Layer;

Δ Θ or Δ ρ: density jump at the top of the MBL (two-layer approximation).

[Tracy Haack, NRL, Tracy.Haack@nrlmry.navy.mil]

Froude Number

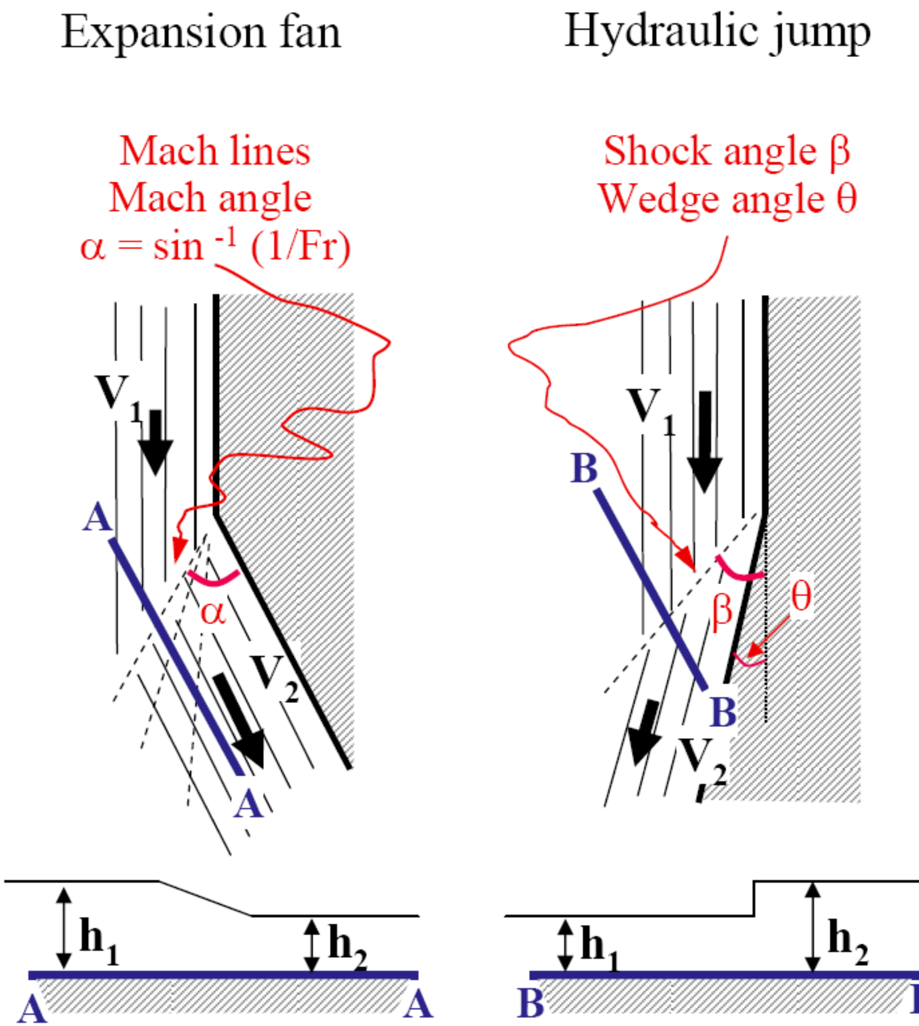
$Fr = V/(g'h)^{1/2}$ $\quad$ $Fr = V/(Nh)$

$g' = g/\theta\,(\Delta\theta)$ $\quad$ $N = (g/\theta\ \partial\theta/\partial z)^{1/2}$

Critical velocity

$Fr = 1.0$

Subcritical	**Supercritical**
$Fr < 1.0$	$Fr > 1.0$



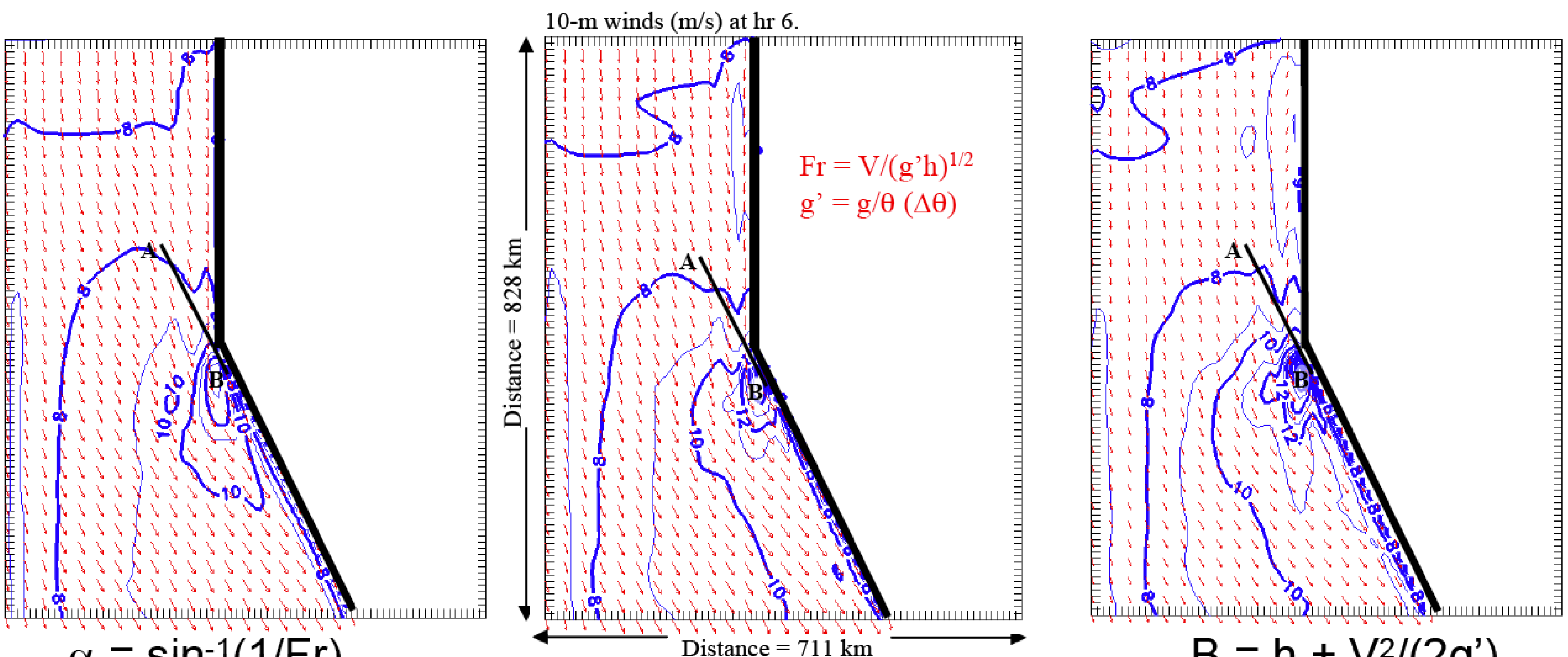
Changing any of these 3 parameters (V, h, Δ Θ) changes the structure of the wind fields, with the greatest variability in the 20-100 km next to the coast.

[Tracy Haack, NRL, Tracy.Haack@nrlmry.navy.mil]

Supercritical case: $\Delta\theta = 5^{o}$

Supercritical case: $\Delta\theta = 10^{o}$

Transcritical case: $\Delta\theta = 20^{o}$



$\alpha = \sin^{-1}(1/Fr)$

$B = h + V^2/(2g')$

Real coasts have multiple "bends", creating multiple hydraulic jumps and expansion fans (as a simple approximation).

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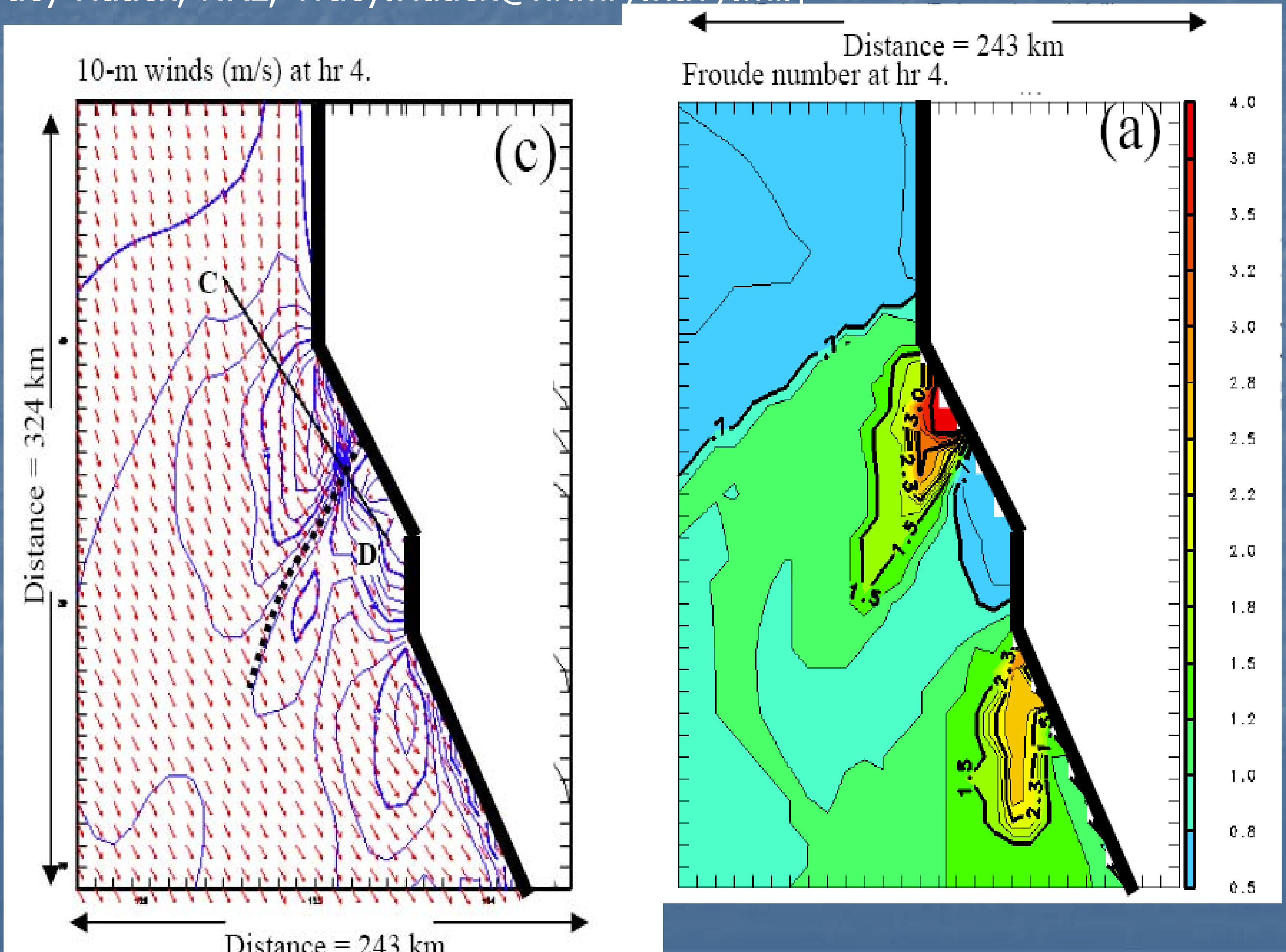


Coastal Winds, Climate and Scatterometry: The Message

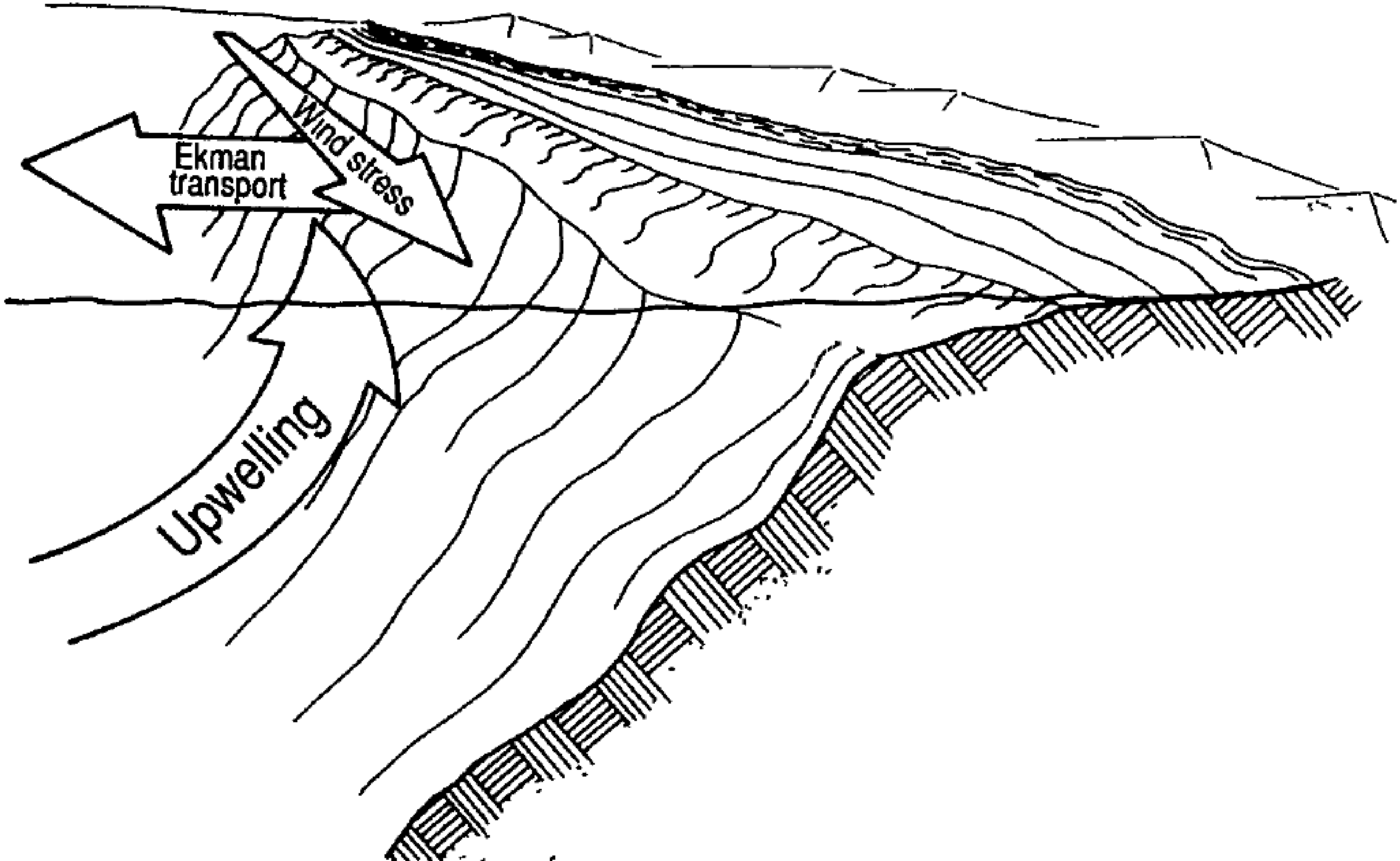
• Coastal wind fields have “small-scale” structure, controlled by the geometry and other characteristics of the land-water boundary, by the strength of the alongshore winds, the height and stratification at the top of the MABL, and by gradients in ocean SST.

• ***The small-scale wind field structure is controlled by <u>alongshore wind speed</u> (plus MABL height and stratification). These parameters change on all time scales: diurnal, synoptic, seasonal, interannual, decadal, `climate change’. The land-sea temperature difference forces much of this variability.***

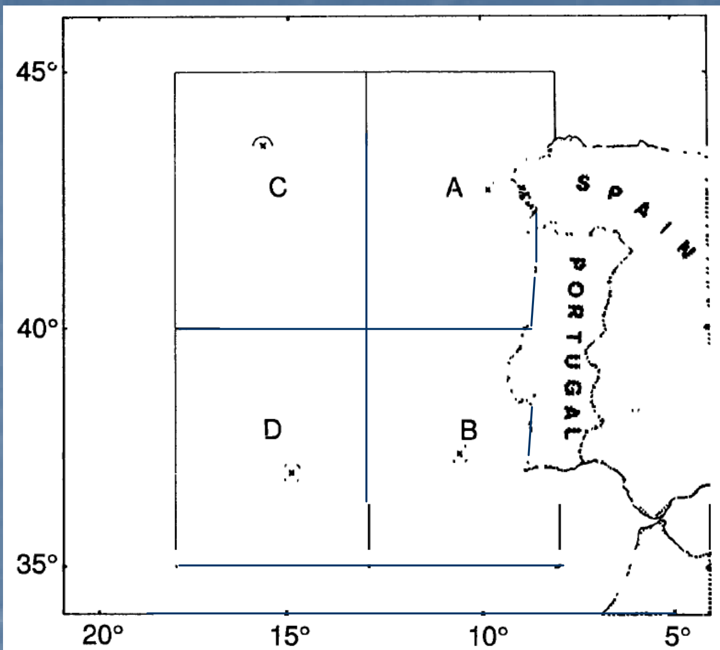
Hypothesized Changes in Coastal Winds Due To Global Warming

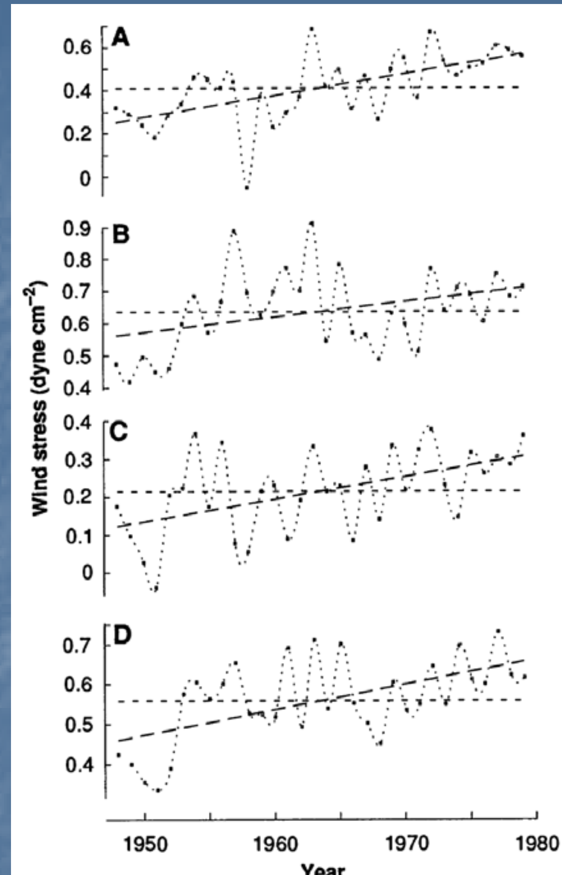
Bakun (1990): Global warming will result in deepened thermal lows in summer over land, next to mid-latitude high pressure systems over the eastern ocean basins, *increasing alongshore wind stress and upwelling.*

High SLP Low SLP



Bakun, 1990: Science, vol. 227, 198-201





Regression Slopes

(Nt m^{-2} per 10 yrs)

Ship Observations

- A: 0.01 Nt m^{-2}
- B: 0.005 Nt m^{-2}
- Peru 0.004 Nt m^{-2}

Pressure-Derived Winds

- NE Atlantic –

  0.001 – 0.004 Nt m^{-2}
- US West Coast –

  0.001 – 0.005 Nt m^{-2}

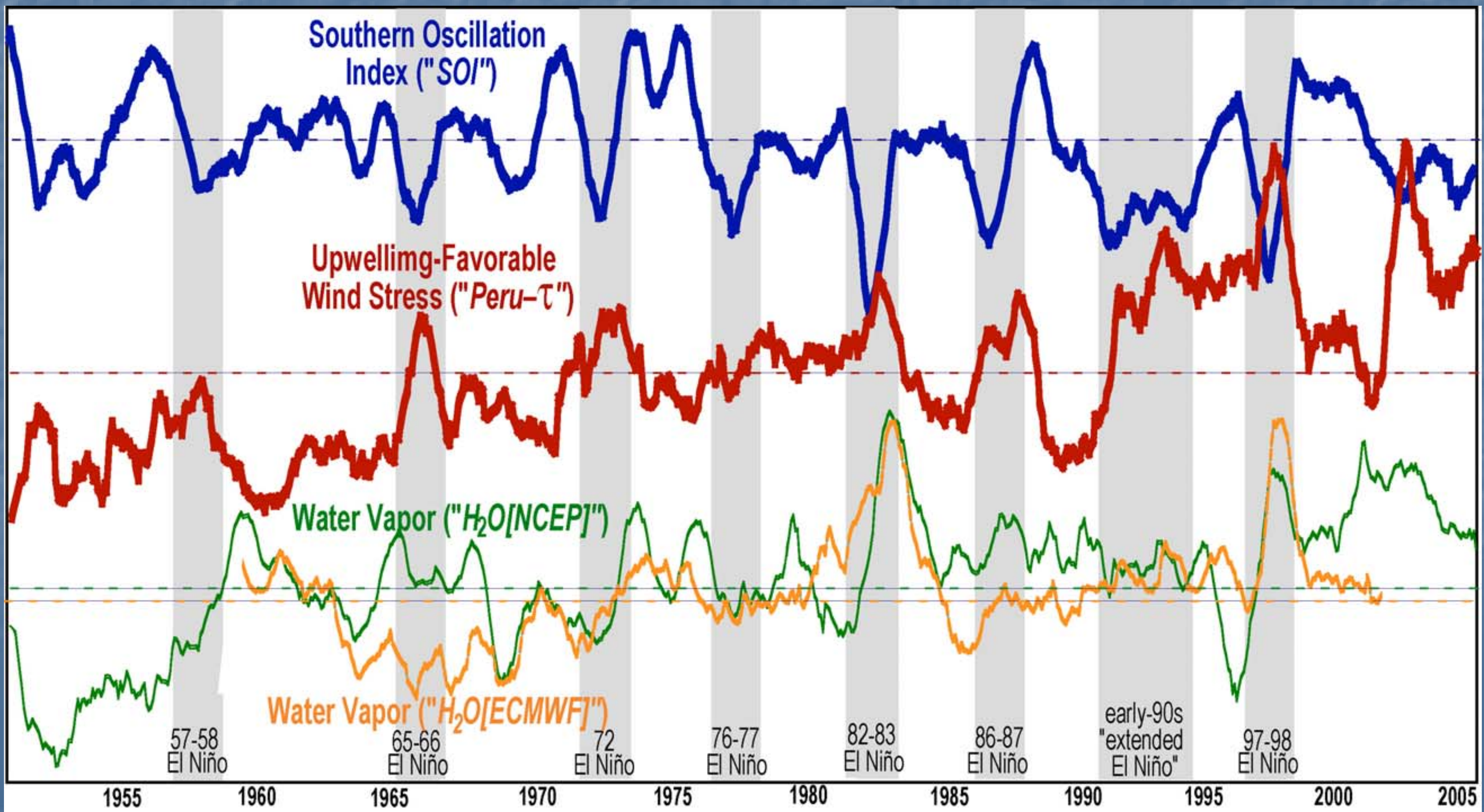
Effects on Large-Scale Ecosystems Depend On

- Strength of upwelling
- Seasonal onset and decline (phenology)
- Persistence and Periodicity (2-6 days on 1-3 days off)

QuikSCAT sampling and accuracy should be able to detect these changes (except HF periodicity?).

Bakun, 2008 (unpublished)

• The magnitude of the alongshore wind stress (red) also varies on interannual time scales. This example is from the Peru coast, where upwelling-favorable winds increase during El Niño events.



Coastal Winds, Climate and Scatterometry: The Message

• Coastal wind fields have “small-scale” structure, controlled by the geometry and other characteristics of the land-water boundary, by the strength of the alongshore winds, the height and stratification at the top of the MABL, and by gradients in ocean SST.

• The small-scale wind field structure is controlled by alongshore wind speed (plus MABL height and stratification). These parameters change on all time scales: diurnal, synoptic, seasonal, interannual, decadal, `climate change’. The land-sea temperature difference forces much of this variability.

•***Details of the wind field structure determine the characteristics of the coastal ocean: location and timing of upwelling maxima; drift patterns for spills of hazardous wastes; transports of eggs and larval stages of fish and invertebrate species, etc. These are of interest to managers responsible for choosing locations for marine sanctuaries, locating ocean wind power generating facilities, anticipating toxic spills, search and rescue, etc.***

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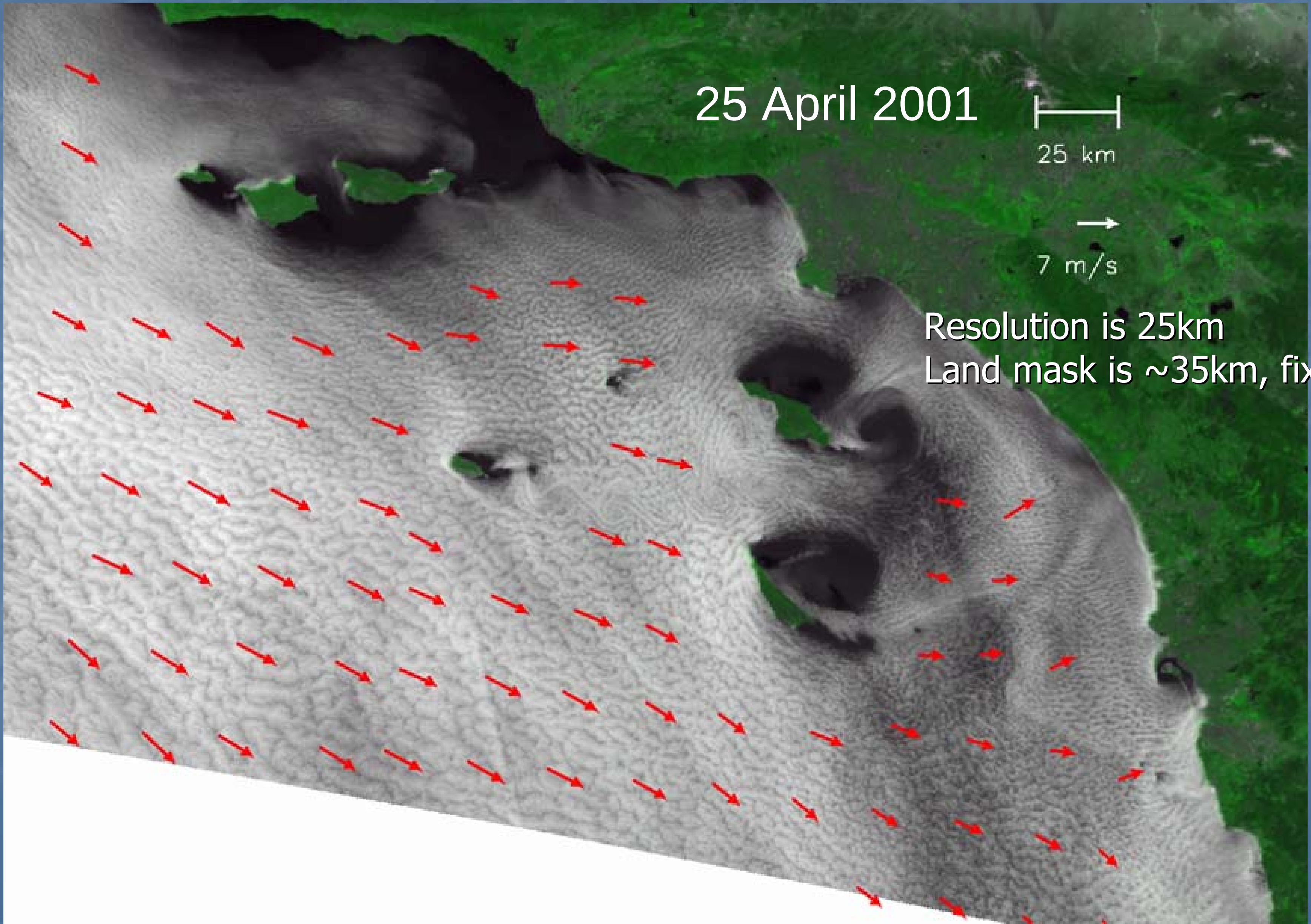
• ***Present scatterometer technology (QuikSCAT, ASCAT) does not resolve the coastal 2-D wind structure well, due to undersampling in both time and space and also due to the coastal gap caused by the land mask.***

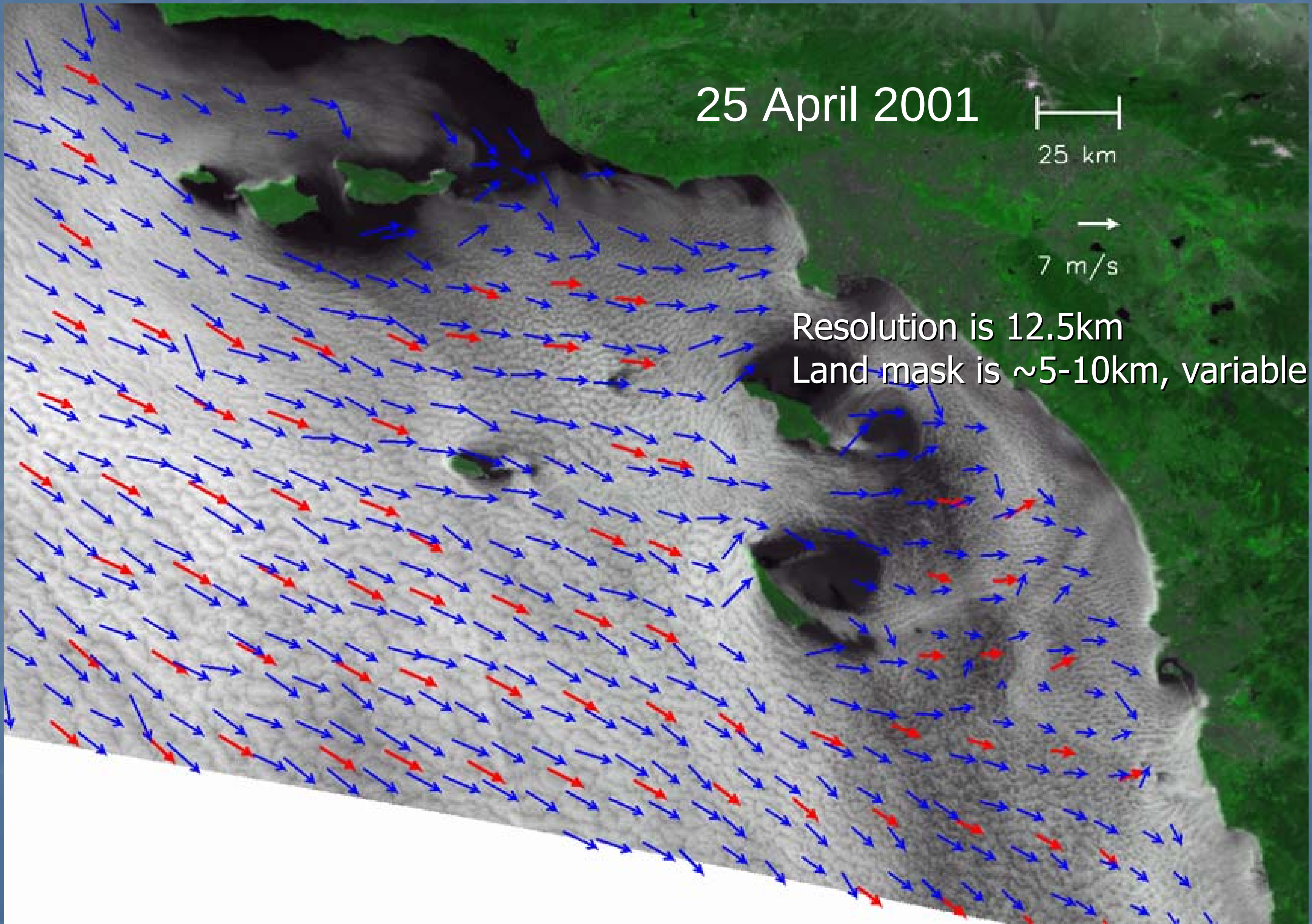
Coastal Zone (0-100 km)

How well does QuikSCAT resolve these changing patterns in the wind fields?



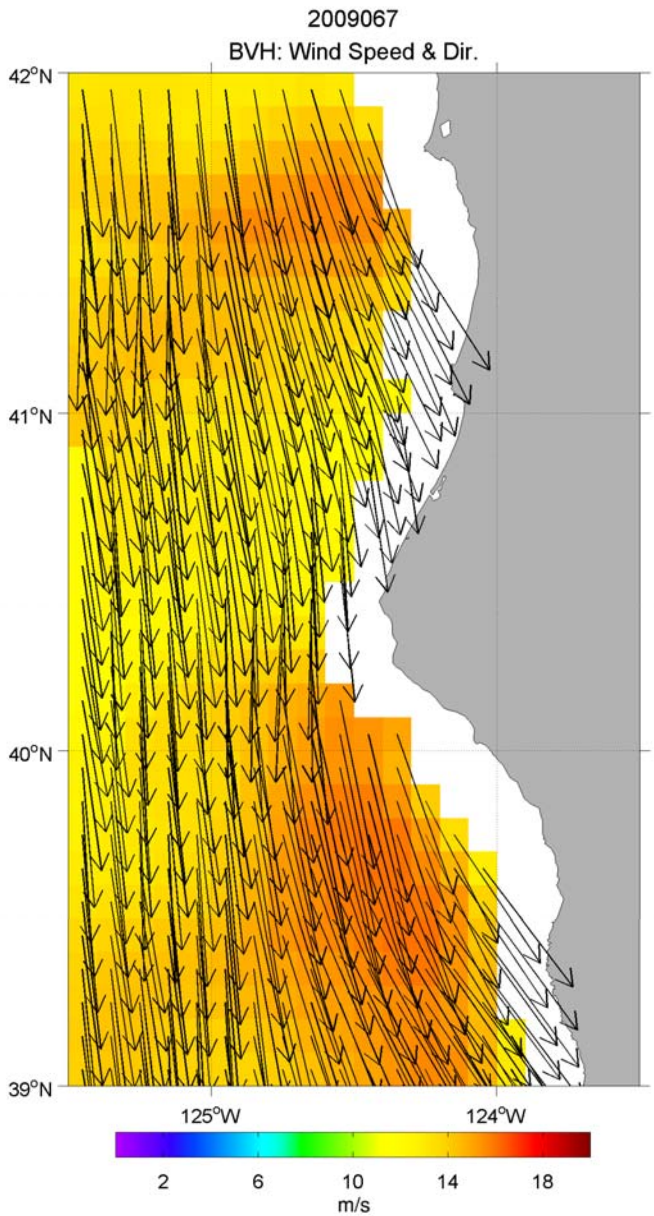
Coastal Zone (0-100 km)

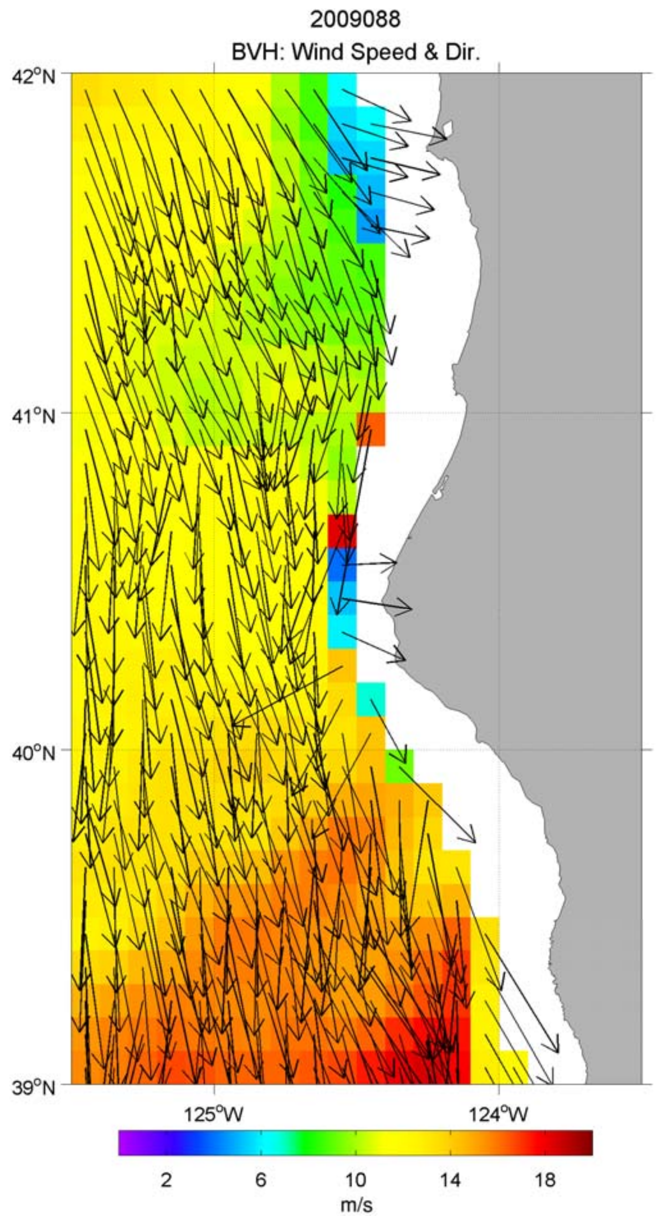
How well does QuikSCAT resolve these changing patterns in the wind fields? A variable land mask can get closer to the coast “sometimes.”



Coastal Zone (0-100 km)

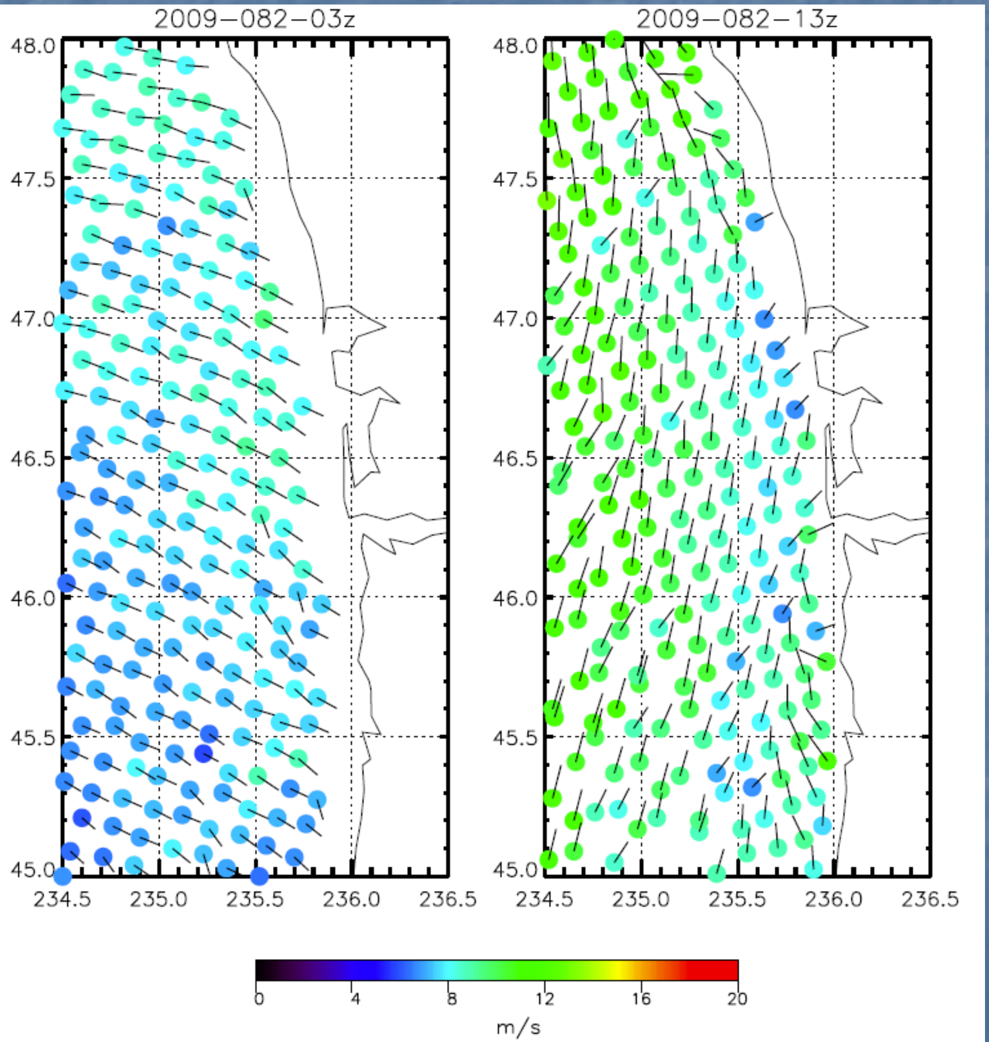
How well does QuikSCAT resolve these changing patterns in the wind fields? The variable land mask creates sampling issues next to the coast.

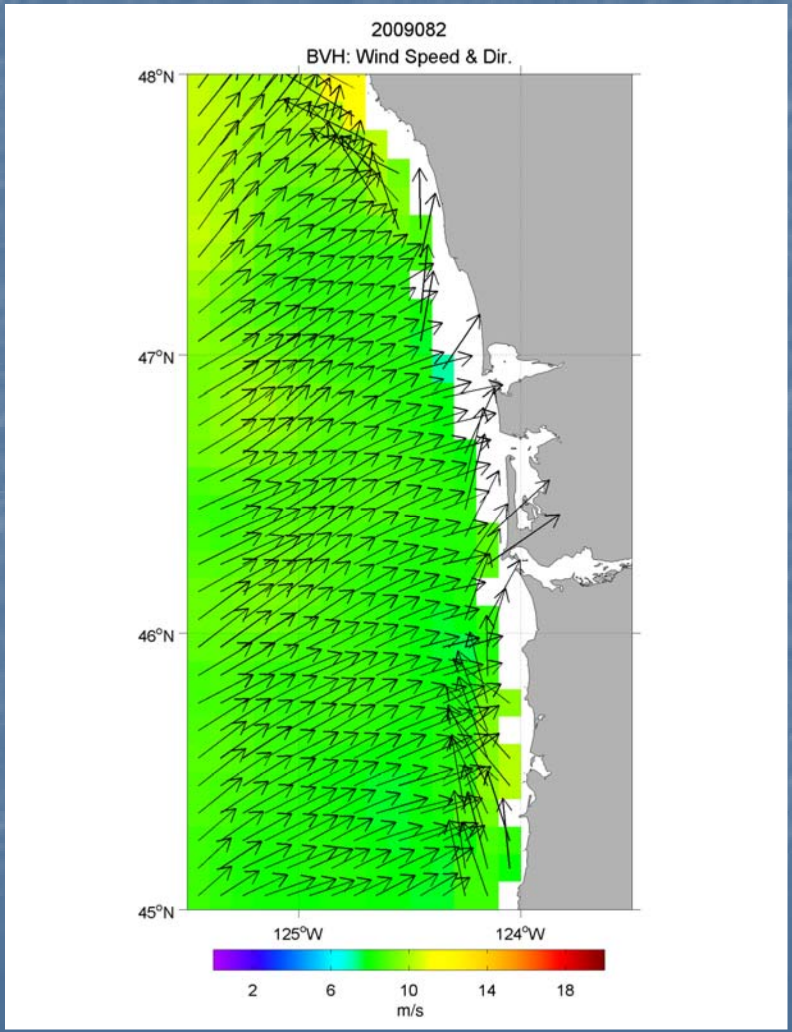




Coastal Zone (0-100 km)

The (temporally) variable land mask creates problems for composites of multiple fields, since sampling of temporal variability varies at each grid point where the new land mask provides data at only some times.





Two fields during day 82 (above left) go into the composite (above right).

Summary: Coastal Winds (0-100 km)

Variability in several parameters causes changes in the high-resolution 2-D patterns of coastal winds on scales from diurnal to centennial.

QuikSCAT does not presently resolve changing patterns in the wind fields within 100 km of the coast very well due to:

- Small-scale structure in the wind fields within the “land-mask gap”
- Rapid changes in this structure with time scales of 6-12 hours
- These high-frequency signals are aliased by sampling of 12-24 hours
- A variable land mask creates discontinuities in composite wind fields in near-shore regions.

Future scatterometers with uniform high-resolution will still create a mismatch caused by higher spatial resolution than temporal resolution. Design of the repeat interval should consider the aliasing of high-frequency atmospheric signals in coastal zones (diurnal to synoptic).

Detecting long-term shifts in high-resolution 2-D wind fields will be difficult using QuikSCAT in the comparison.

High-resolution coastal wind models may be of use in providing some of the HF changes in coastal wind fields (as for altimetry), perhaps extending back to the QuikSCAT period.

Coastal Winds, Climate and Scatterometry: The Message

• Coastal wind fields have "small-scale" structure, controlled by the geometry and other characteristics of the land-water boundary, by the height and stratification at the top of the MABL, and by gradients in ocean SST.

• These characteristics, and the small-scale wind field structure they control, change on all time scales: diurnal, synoptic, seasonal, interannual, decadal, `climate change'.

• Details of the wind field structure determine the characteristics of the coastal ocean: location and timing of upwelling maxima; drift patterns for spills of hazardous wastes; transports of eggs and larval stages of fish and invertebrate species, etc. These are of interest to managers responsible for choosing locations for marine sanctuaries, locating ocean wind power generating facilities, anticipating toxic spills, search and rescue, etc.

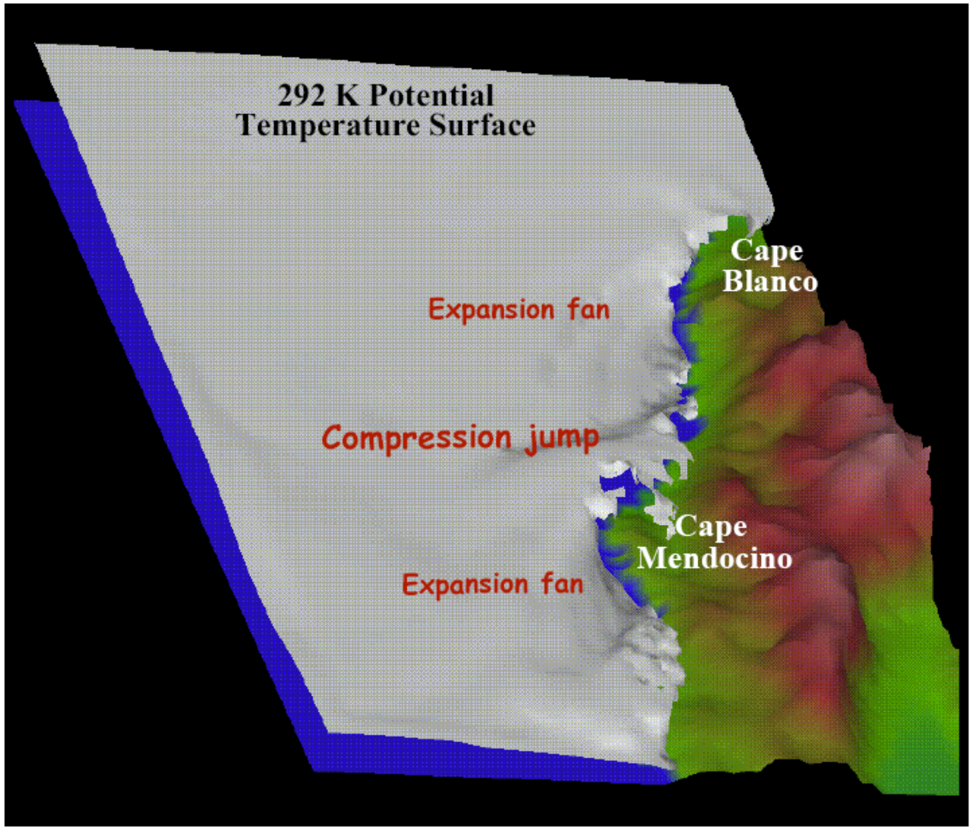
• Present scatterometer technology (QuikSCAT, ASCAT) does not resolve the coastal 2-D wind structure well, due to undersampling in both time and space and also due to the coastal gap caused by the land mask.

• Future, high-resolution scatterometer fields may resolve the spatial structure during snapshots, but will still undersample the diurnal and synoptic variability.

• Modeling the higher-frequency signals (as with altimetry) may help.

Real Data Case Studies

CW96: 12 June 1996

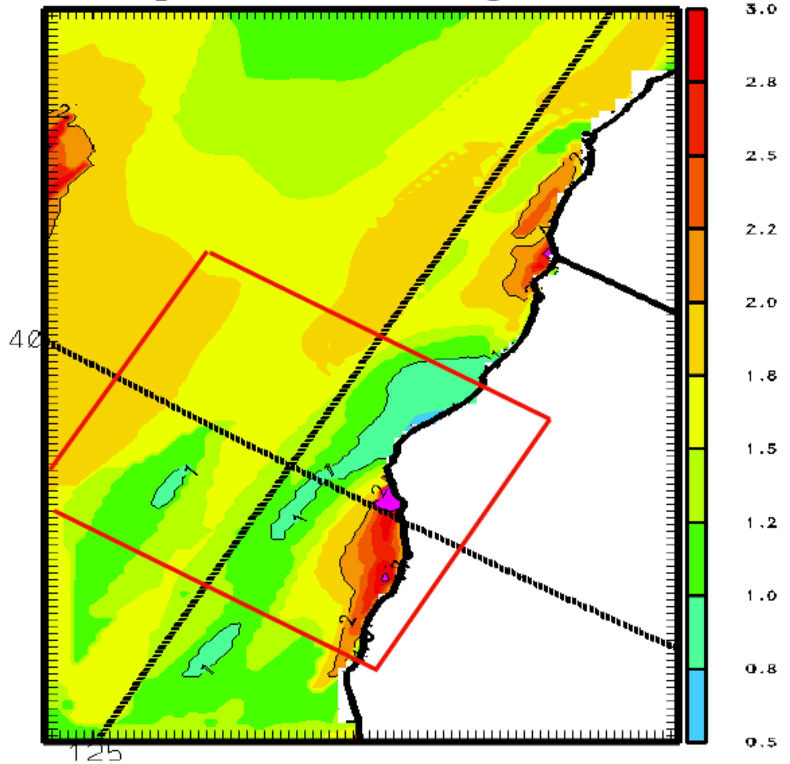


Marine boundary layer depth features

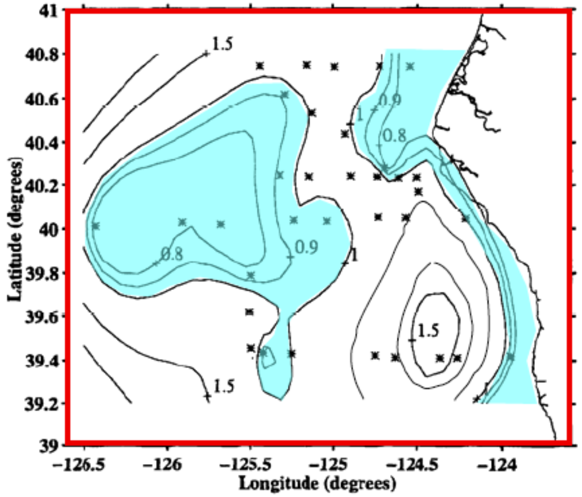
$$Fr = V/(g'h)^{1/2}$$

$$g' = g/\theta \, \Delta\theta$$

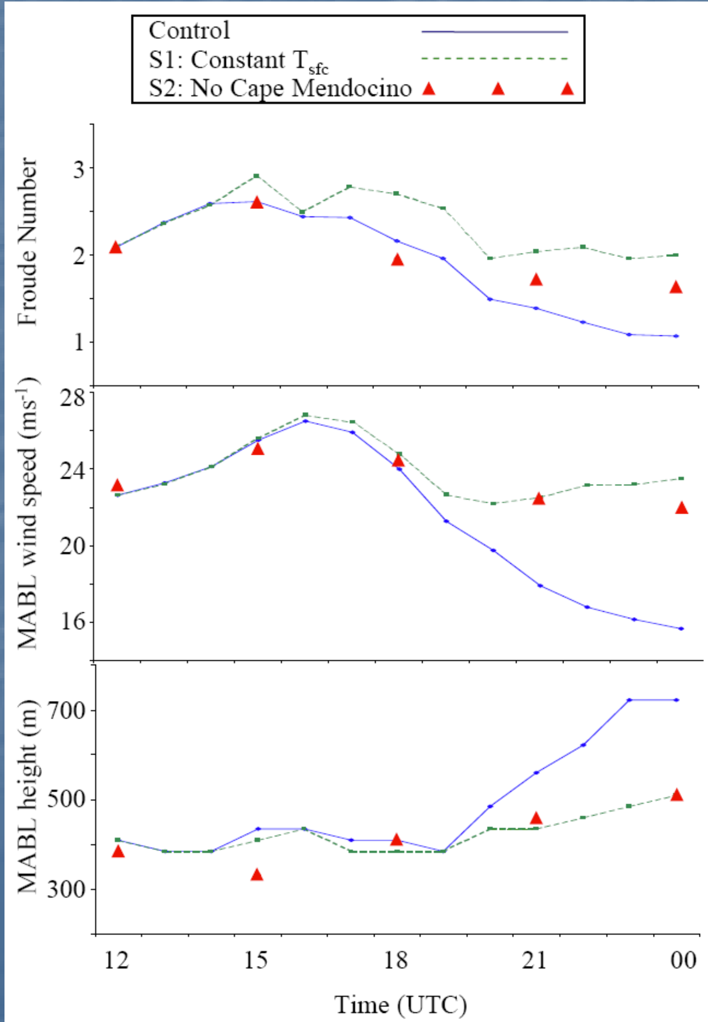
Model computed values from grid 3 valid 00 UTC



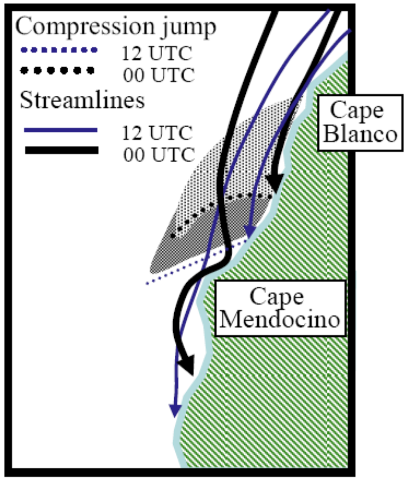
C-130 flight data (Rogers et al., 98)



Changes in land surface temperature change MABL wind speed and height, and thus the 2-D wind distribution on diurnal and longer time scales. These change the locations of upwelling maxima and horizontal transports in the ocean, as well as wind mixing and power maxima, etc., relative to coastal features. Local communities, Coast Guard, maritime transportation, etc would like to know what to expect with respect to these changes.
[Tracy Haack, NRL, Tracy.Haack@nrlmry.navy.mil]



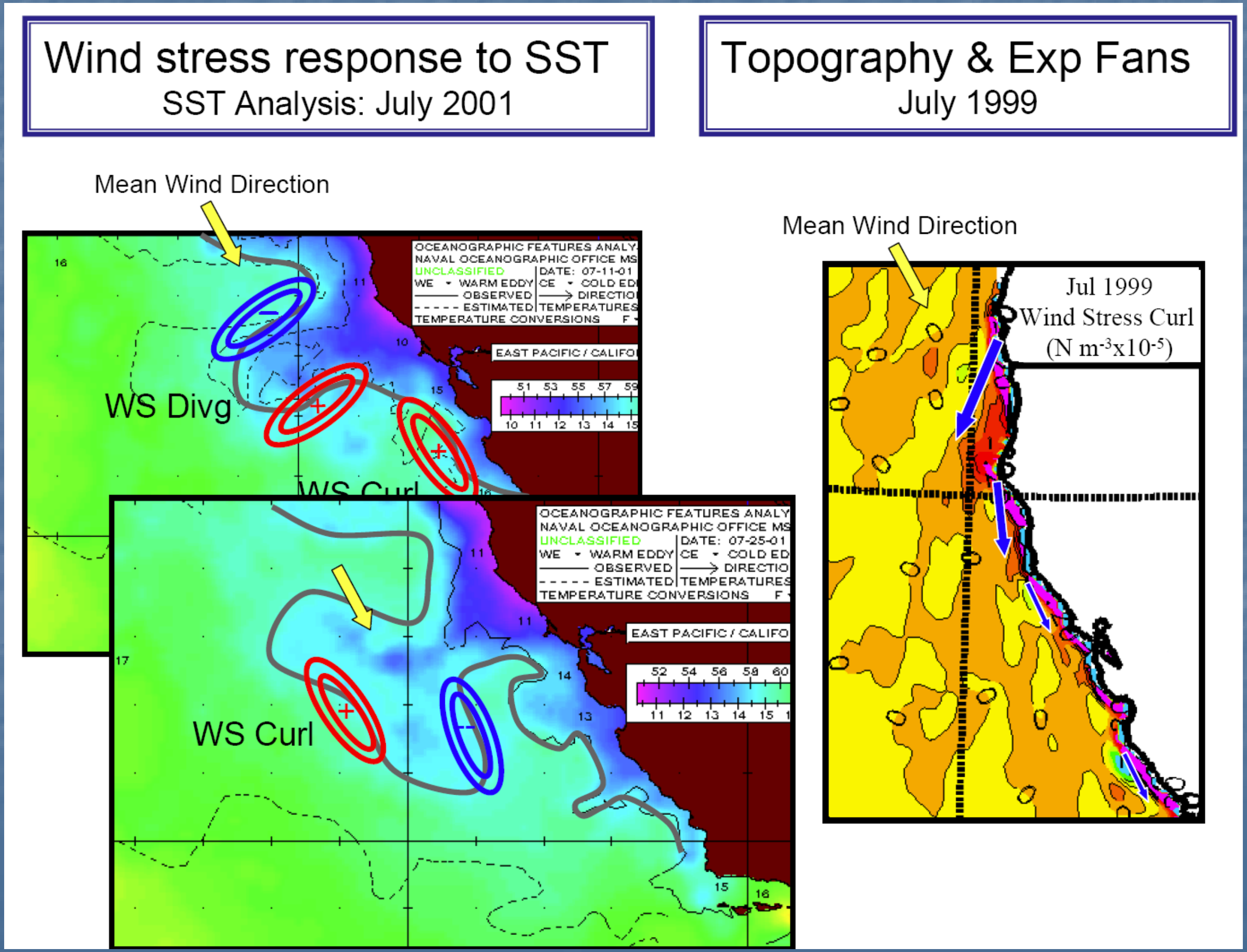
- **The position and shape of the compression jump is sensitive to diurnal variations in upwind (expansion fan) conditions.**



Diurnal trends due to sea/land breeze

Two Spatial Regimes:

Coastal: 0-100 km, dominated by hydraulic flow effects (Fr #)
Offshore: 100+ km, winds modulated by SST (warm SST, higher wind speeds). [Tracy Haack, NRL, Tracy.Haack@nrlmry.navy.mil; Dudley Chelton]



Two Spatial Regimes:

Correlations of wind stress curl and divergence to SST gradients decrease next to the coast where hydraulic effects dominate.

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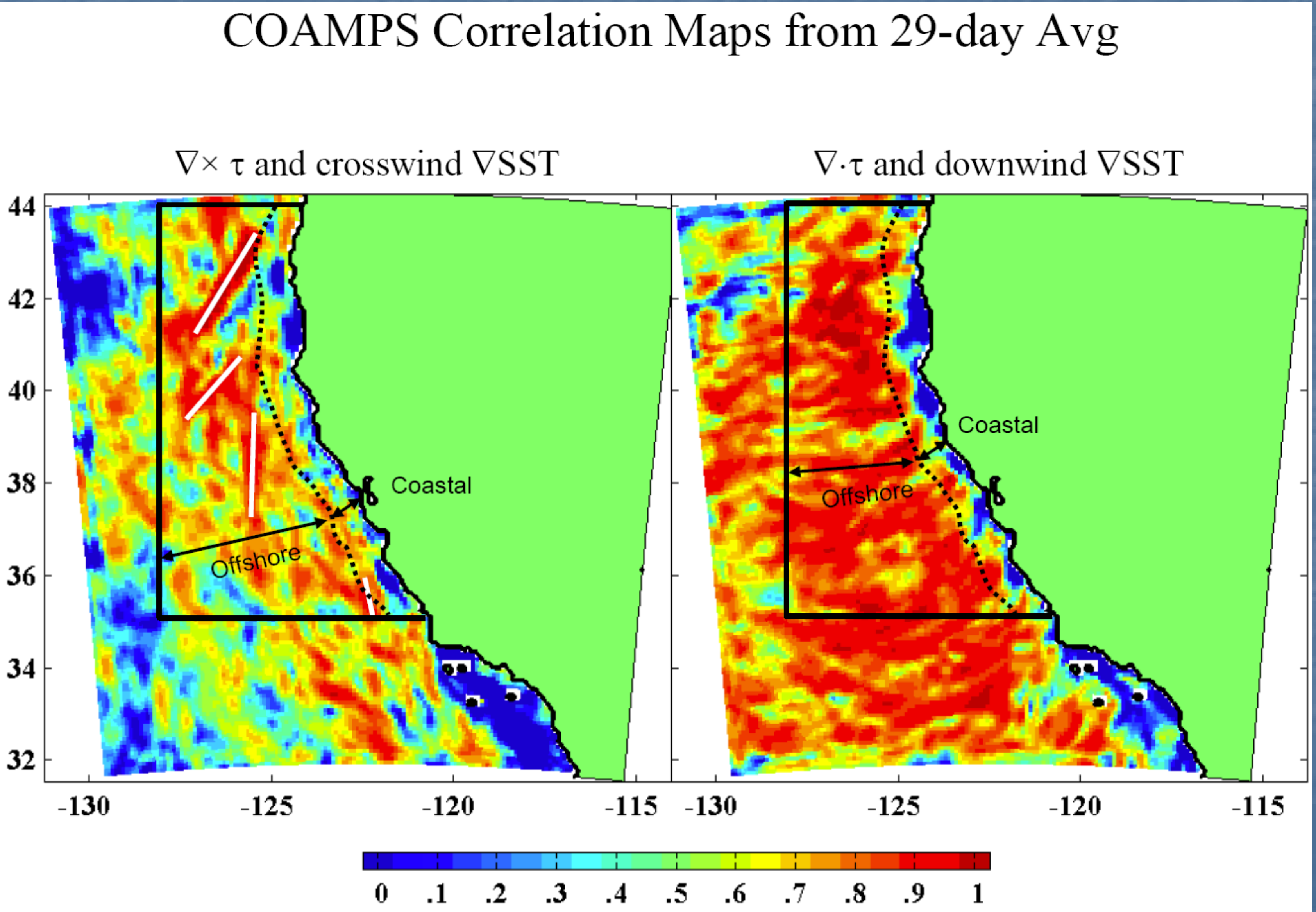

Coastal Zone (0-100 km)

How well does QuikSCAT resolve these changing patterns in the wind fields?

Below are “weekly” means centered on March 23, 2009, reducing the number of “required” days from 6 to 2.

6 days 5 days 4 days 3 days 2 days