# Summary of Science Thoughts for Possible Future NASA Missions, Part I

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Dudley Chelton, Alex Fore, Peter Gaube,
Michelle Gierach, Tony Lee, Jim McWilliams,
Larry O'Neill, Dragana Perkovic, Bryan Stiles,
Svetla-Hristova Veleva, Duane Waliser, Brent Williams,
Shang-Ping Xie, and Simon Yeuh

coastal winds, Latent and sensible heat, atmospheric convection, and perhaps tropical cyclones.

# Background

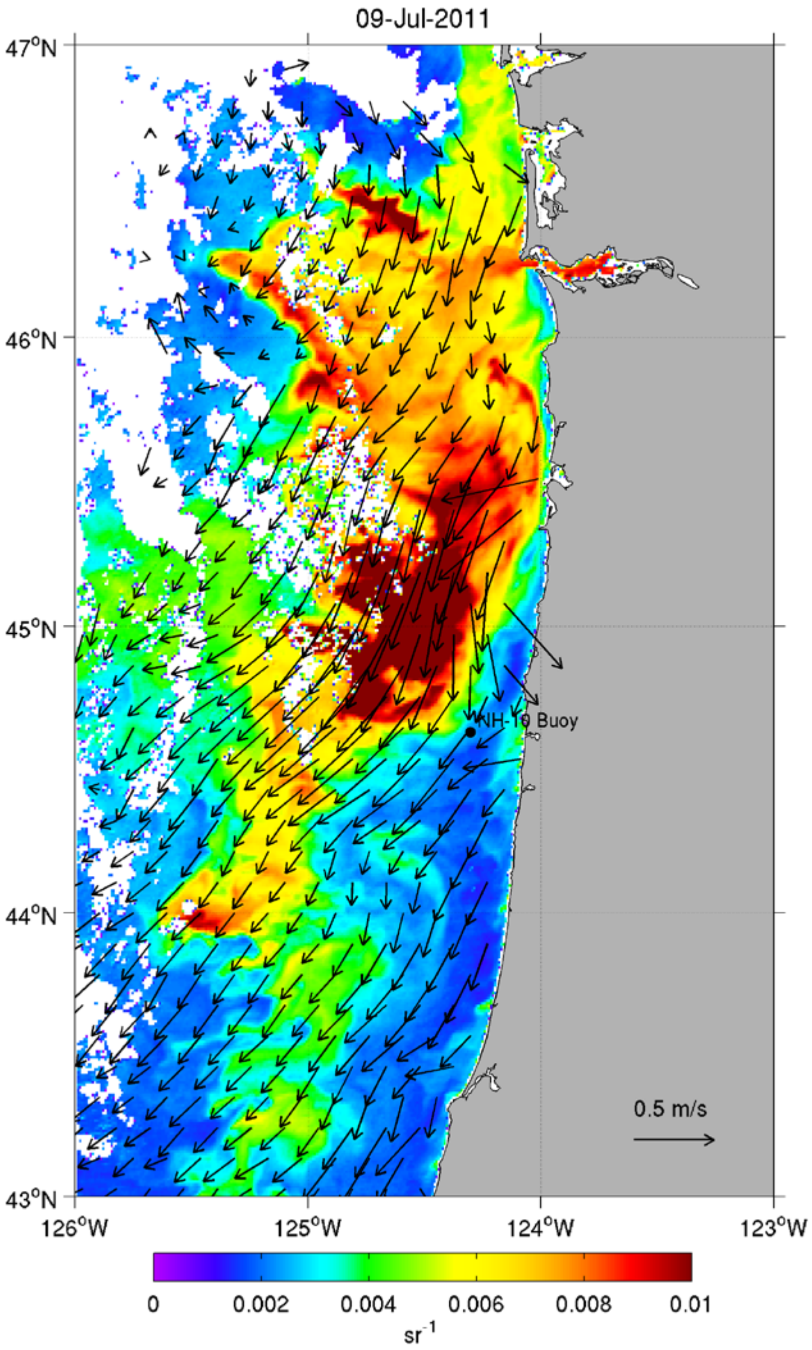
- NASA requested a white paper to examine scientific objectives and mission options for a potential next-generation science-driven OVW scatterometer.
  - Goal: to present a range of science questions that would advance NASA's Earth science goals and that go beyond the science questions driving current scatterometer missions.
  - Based on a very limited set of satellite options and a limited budget
- Sources of Input:
  - The National Research Council Decadal Review recommendations for the XOVWM instrument (National Research Council, 2007),
  - The ocean vector wind community paper for OceanObs 2009 (Bourassa et al., 2010), and
  - Results of an invited meeting held at the Jet Propulsion Laboratory in January 2012.
- The goals presented here are from a limited science team, mindful of the community consensus, and have not yet received endorsement from the NASA Ocean Vector Winds Science Team (OVWST).

# Intent of the White Paper

- The draft of this white paper is to serve as a spring-board for larger community input.
- The hope is that the final white paper will be a useful document for outlining science-driven options for the next generation scatterometer.
  - The current draft is limited in coverage of the science issues that might be impacted by such a system
  - The community at large, and particularly the International Ocean Vector Winds Science Team, is encouraged to contribute towards making this a better document.

# Broad Themes of The Original Paper

- Decadal and Longer Climate Variability
- Diurnal and Sub-Diurnal Winds and Constellation Cross-Calibration
- High Resolution Winds
- Driving Science Questions
  - The Ocean Vector Wind Climate Data Record
  - Sub-Daily Wind Variability
  - The Impacts of Scatterometry on Numerical Weather Prediction Models
  - Scatterometer Constellation Cross-Calibration
  - Coastal Winds
  - Influence of Mesoscale SST Fronts on Surface Winds
  - Mesoscale Eddy Influence on the Surface Stress and Oceanic Chlorophyll
  - Ocean Productivity, Sea Surface Temperature, and Ocean Vector Winds
  - Latent and Sensible Heat Fluxes
  - Atmospheric convective system
  - High Resolution and Rain Flagging
  - Rain Estimation Using Ku and Ka Scatterometry and AMSR
  - Tropical Cyclones



# July 9, 2011

(colors) MODIS 555nm related to suspended sediment

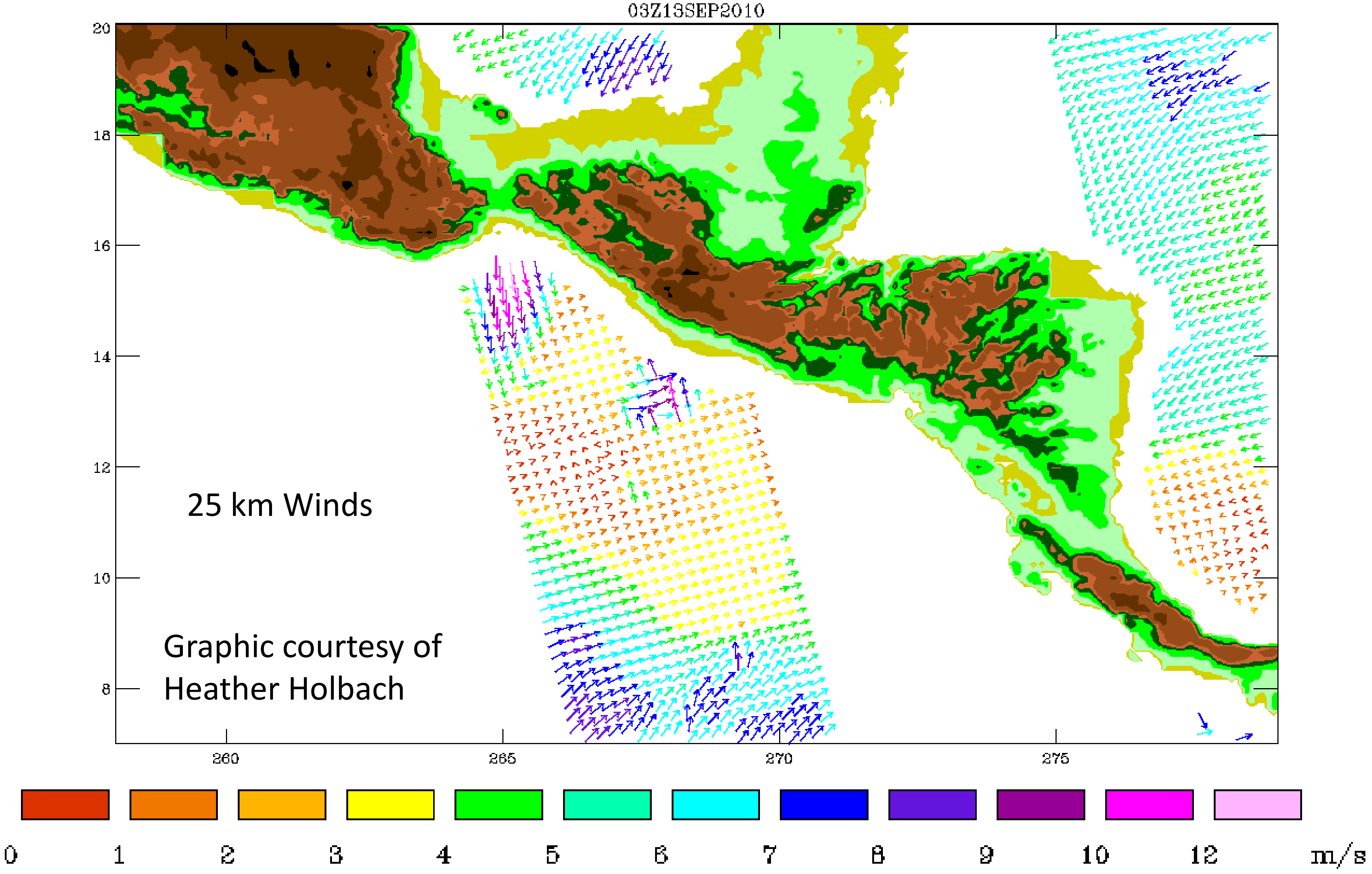
(vectors) HF radar estimates of surface currents

Large Columbia River plume advected southward produced some of the lowest salinity and dissolved oxygen values measured off the Oregon coast

High-resolution wind field near the coast would be valuable from a fisheries perspective to estimate future path of plume as surface currents respond fairly quickly (O~1 day) to along-shore wind changes

Image courtesy of Craig Risien, ORCOOS/OSU

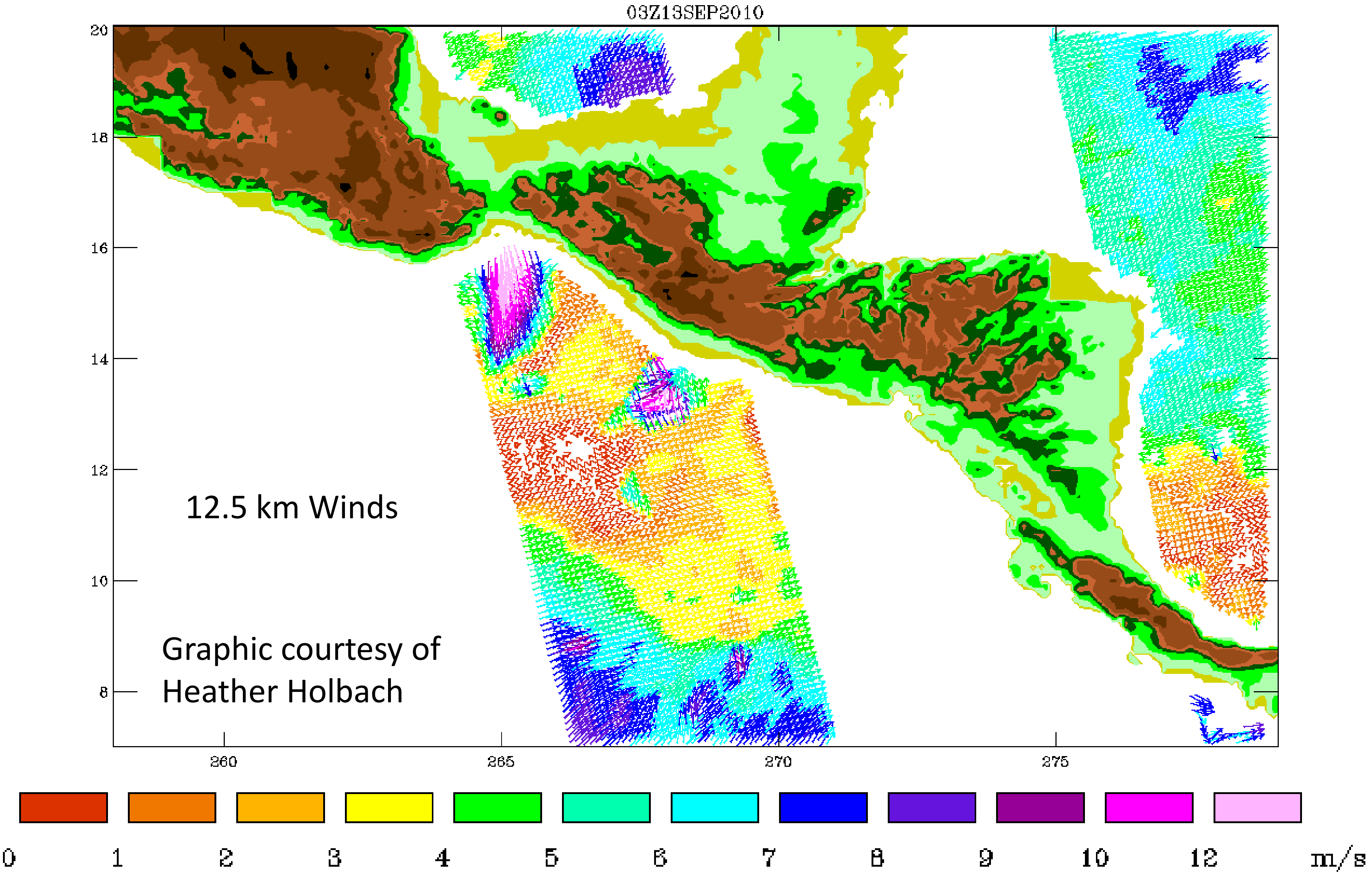
# Gap Flow Winds from Central America



25 km Winds

Graphic courtesy of
Heather Holbach

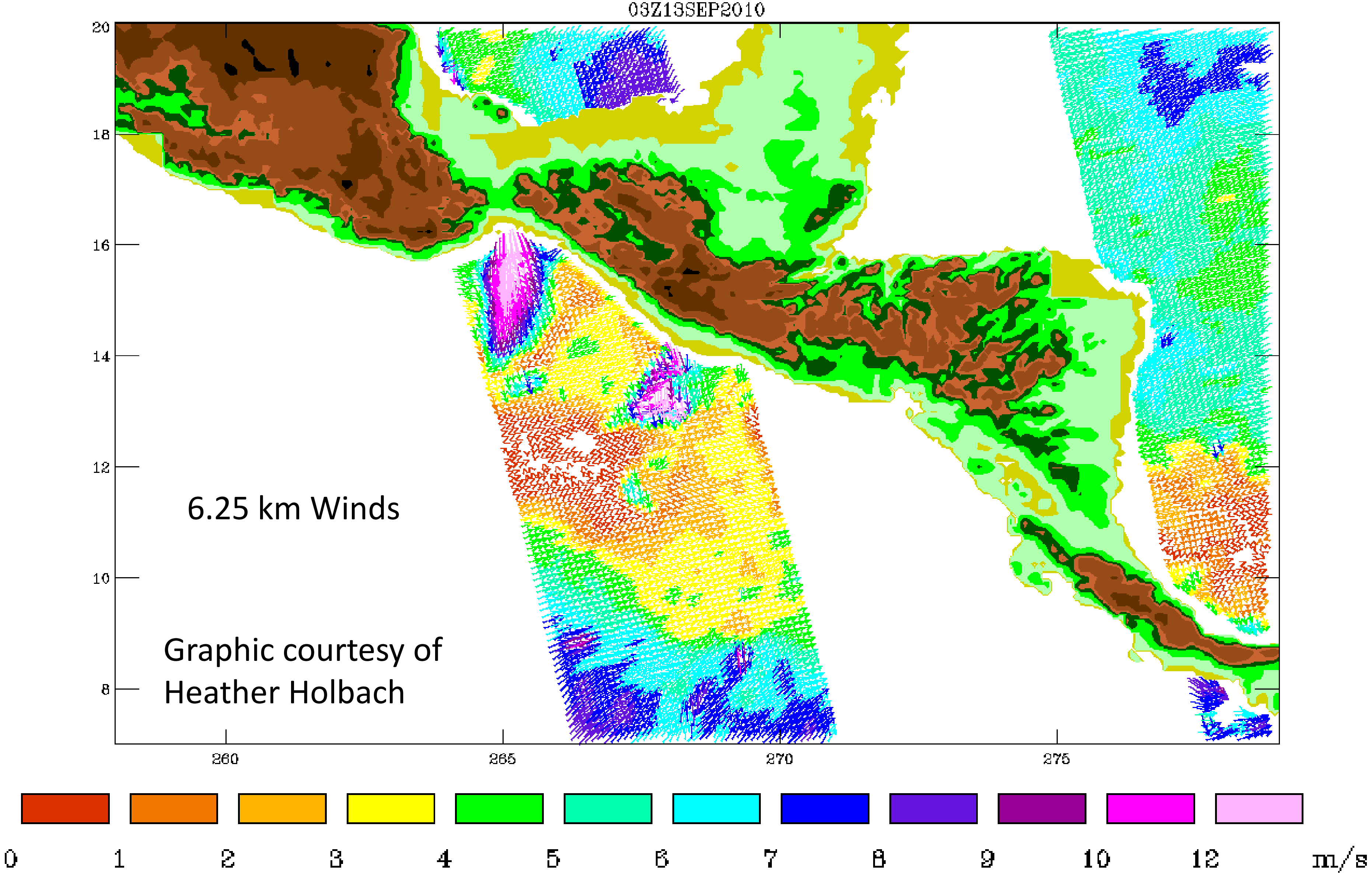
# Gap Flow Winds from Central America



12.5 km Winds

Graphic courtesy of
Heather Holbach

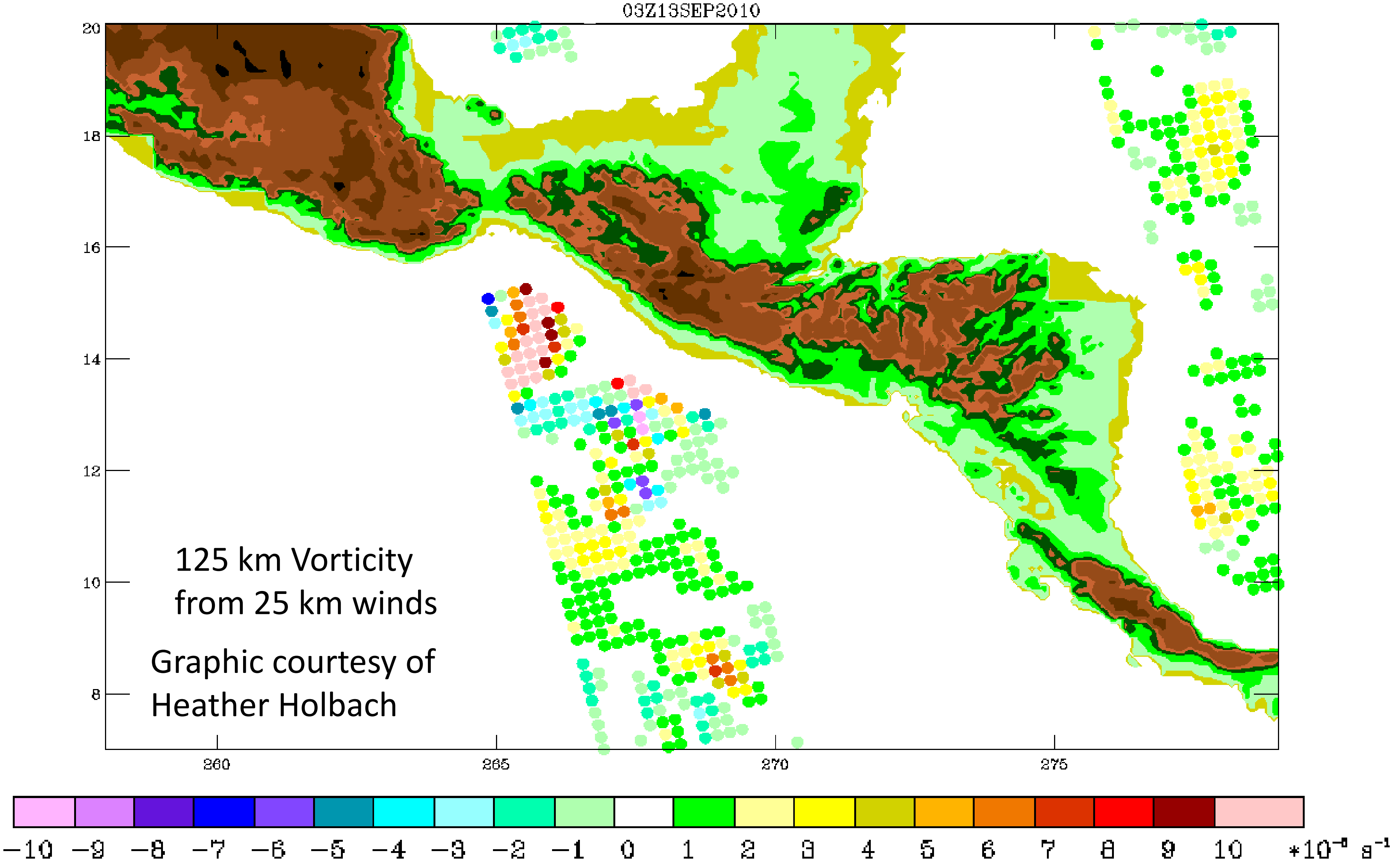
# Gap Flow Winds from Central America



6.25 km Winds

Graphic courtesy of
Heather Holbach

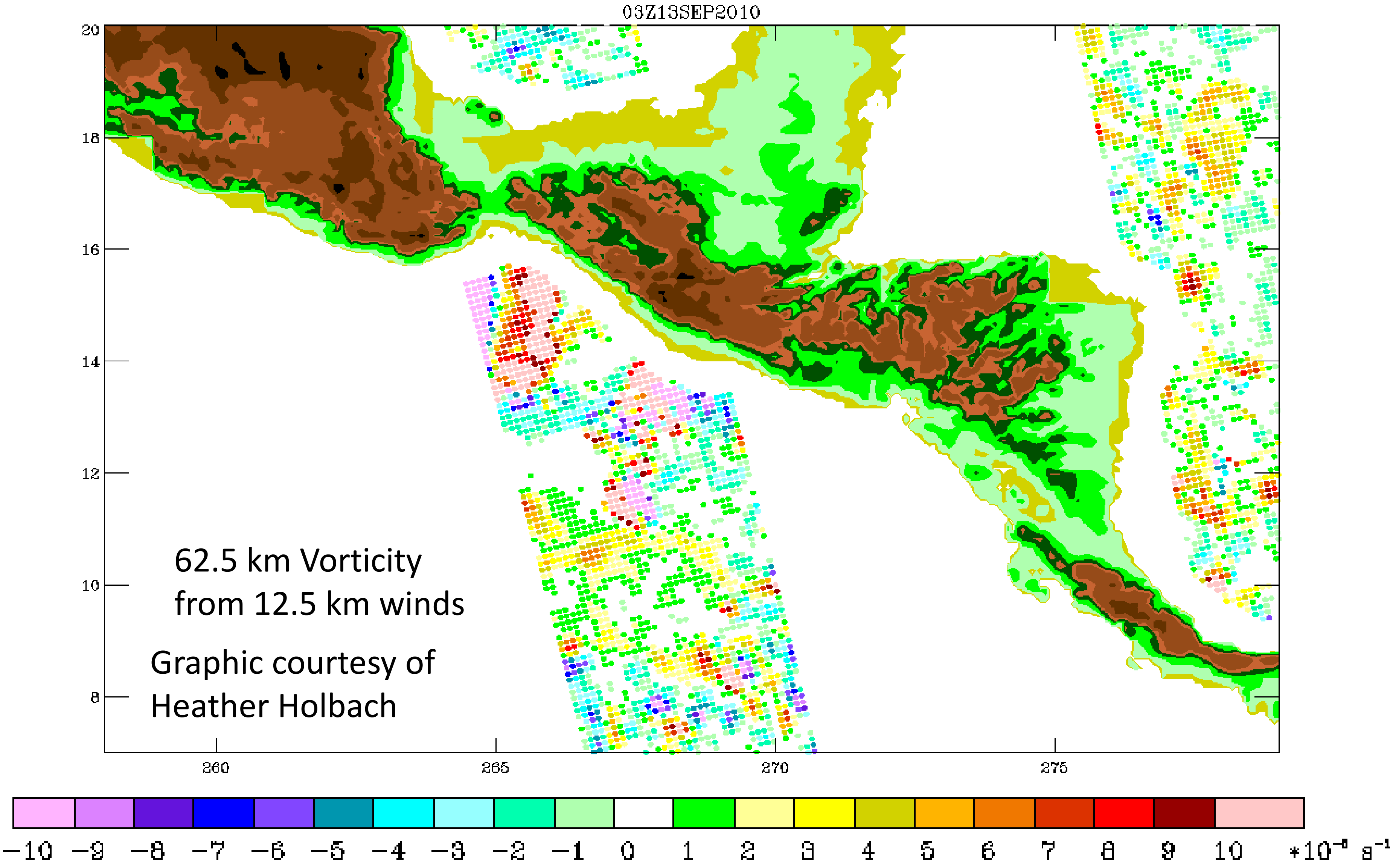
# Curl of Gap Flow Winds from Central America



125 km Vorticity
from 25 km winds

Graphic courtesy of
Heather Holbach

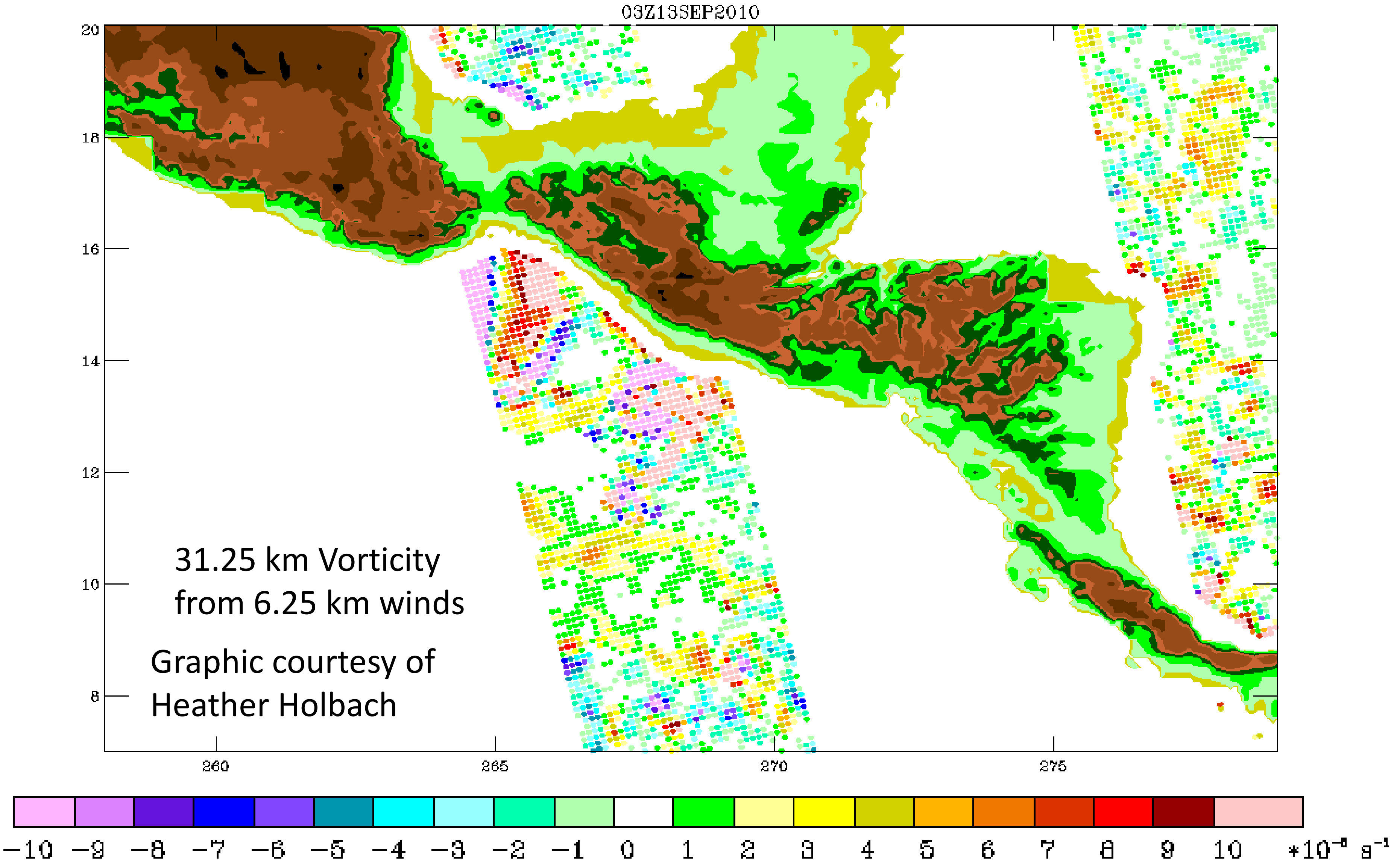
# Curl of Gap Flow Winds from Central America



62.5 km Vorticity
from 12.5 km winds

Graphic courtesy of
Heather Holbach

# Curl of Gap Flow Winds from Central America



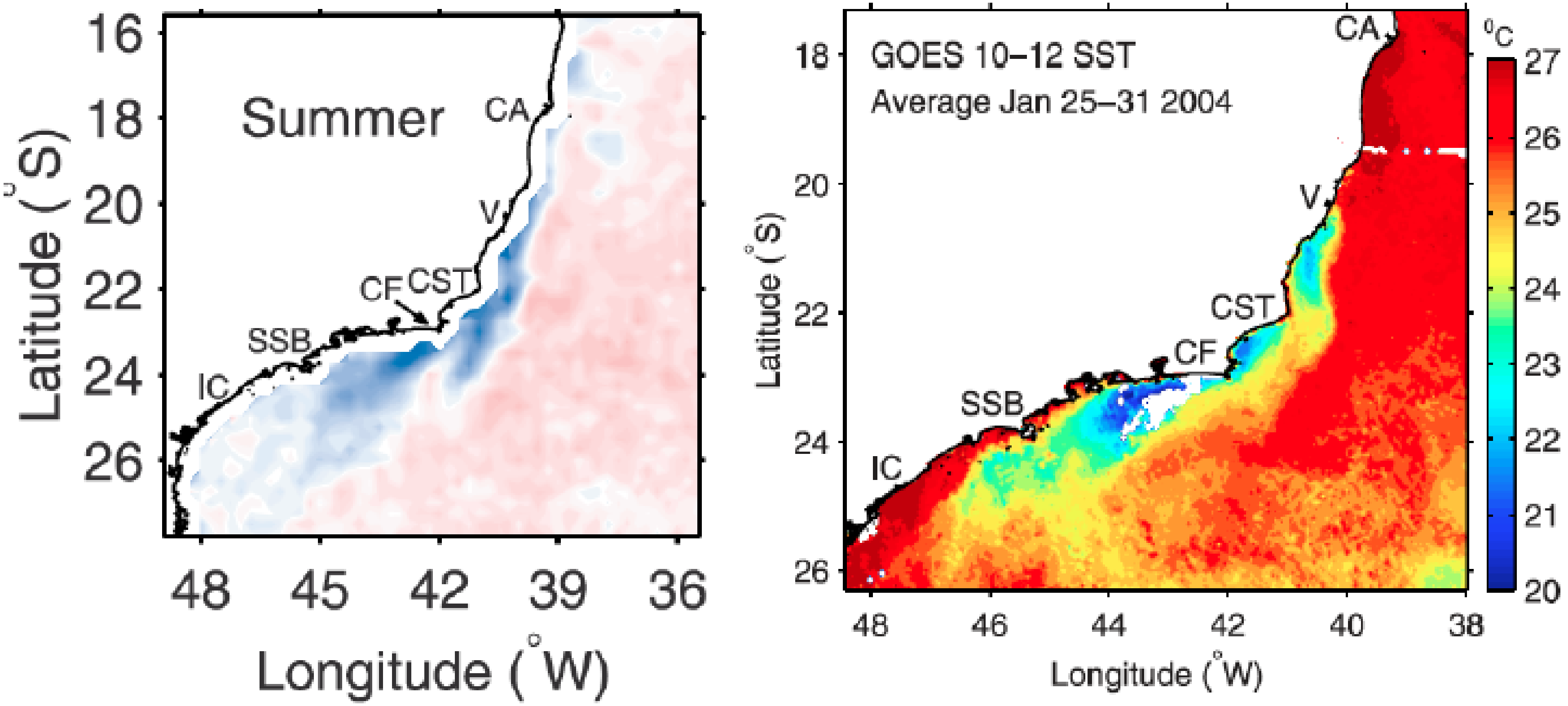
31.25 km Vorticity
from 6.25 km winds

Graphic courtesy of
Heather Holbach

# Comments

- The air/sea interaction in coastal regions has a great deal of societal interest
  - Fisheries
  - Extreme weather
  - Forecasts of for coastal winds, waves and sea surface temperature
- High resolution winds are needed for near coastal applications
  - They are also likely to be important in areas of
    - Strong SST gradients
    - Atmospheric fronts
    - For examining river outflow
    - Orographic forcing of winds
- For derivatives on spatial scales less than three grid cells, the noise has a relatively huge impact
- A finer resolution is very useful for producing less noisy area averaged vorticity
  - If the curl of the stress on a 25km scales is important to ocean forcing, then winds (stress) should be resolved on a 8.3 km scale or finer.
  - For coastal work, we would like vorticity on finer scales, and hence need finer scale winds.

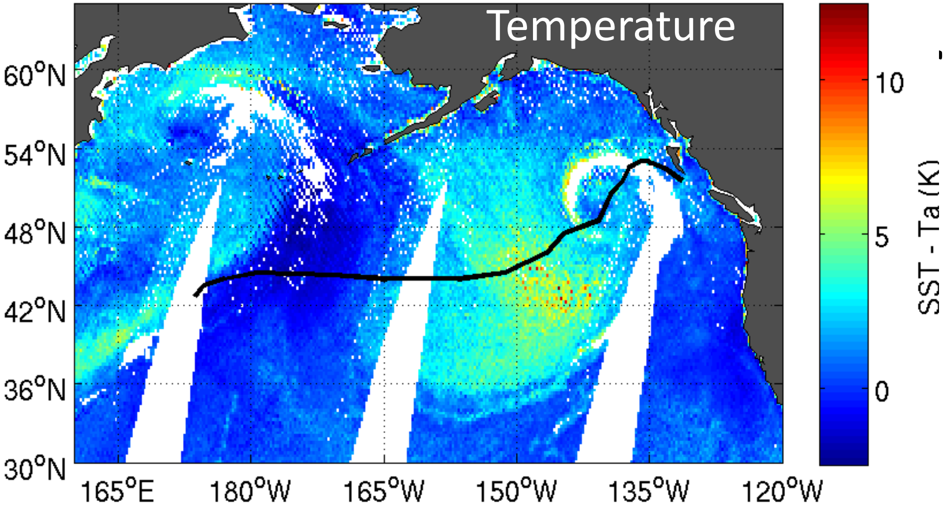
# Cape Wind Curl and Local Upwelling

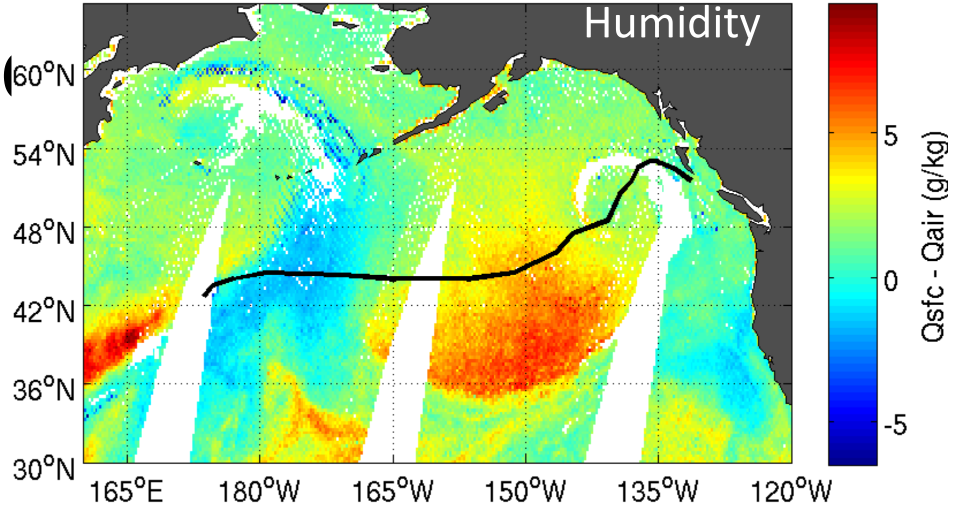


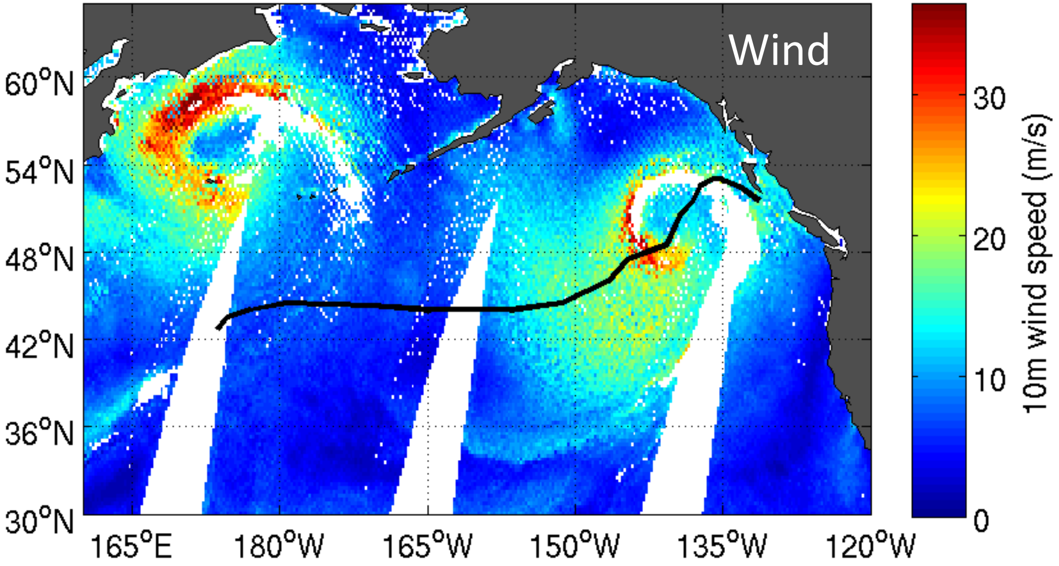
Summertime upwelling around Cabo Frio, Brazil, in response to wind separation from the coast over a width $\sim$ 200 km (Castelao and Barth, *GRL*, 2006). Wind curl [$\sim\ 3 \times 10^{-7}$ N/m$^3$] is from QuikSCAT, and SST [$\sim\ 4$ C] is from GOES 10-12.

Input from James McWilliams

# Warm Core Seclusion Air/Sea





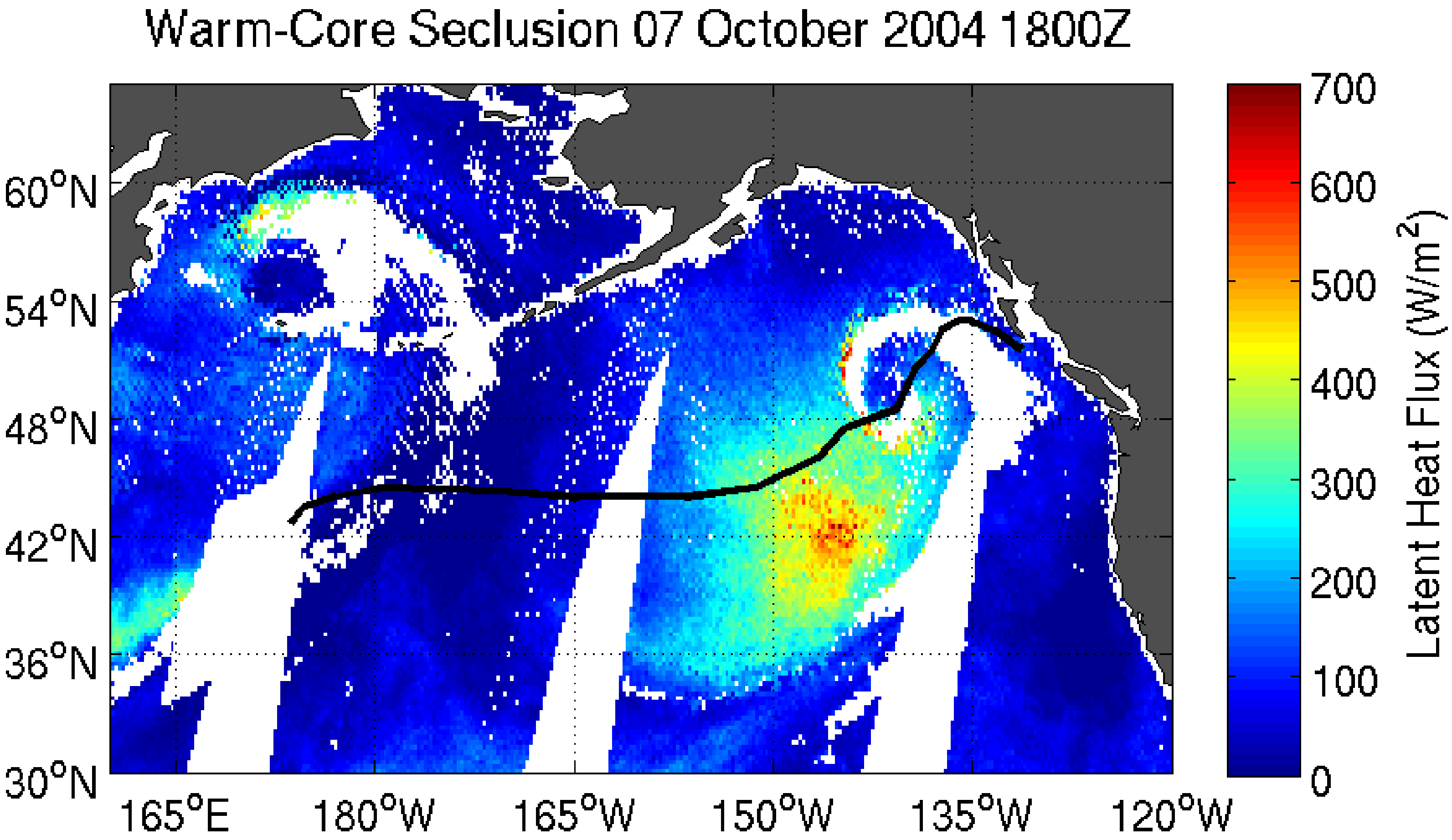


Graphics courtesy of Joel Scott

# Example LHF Retrieval: Warm Core Seclusion

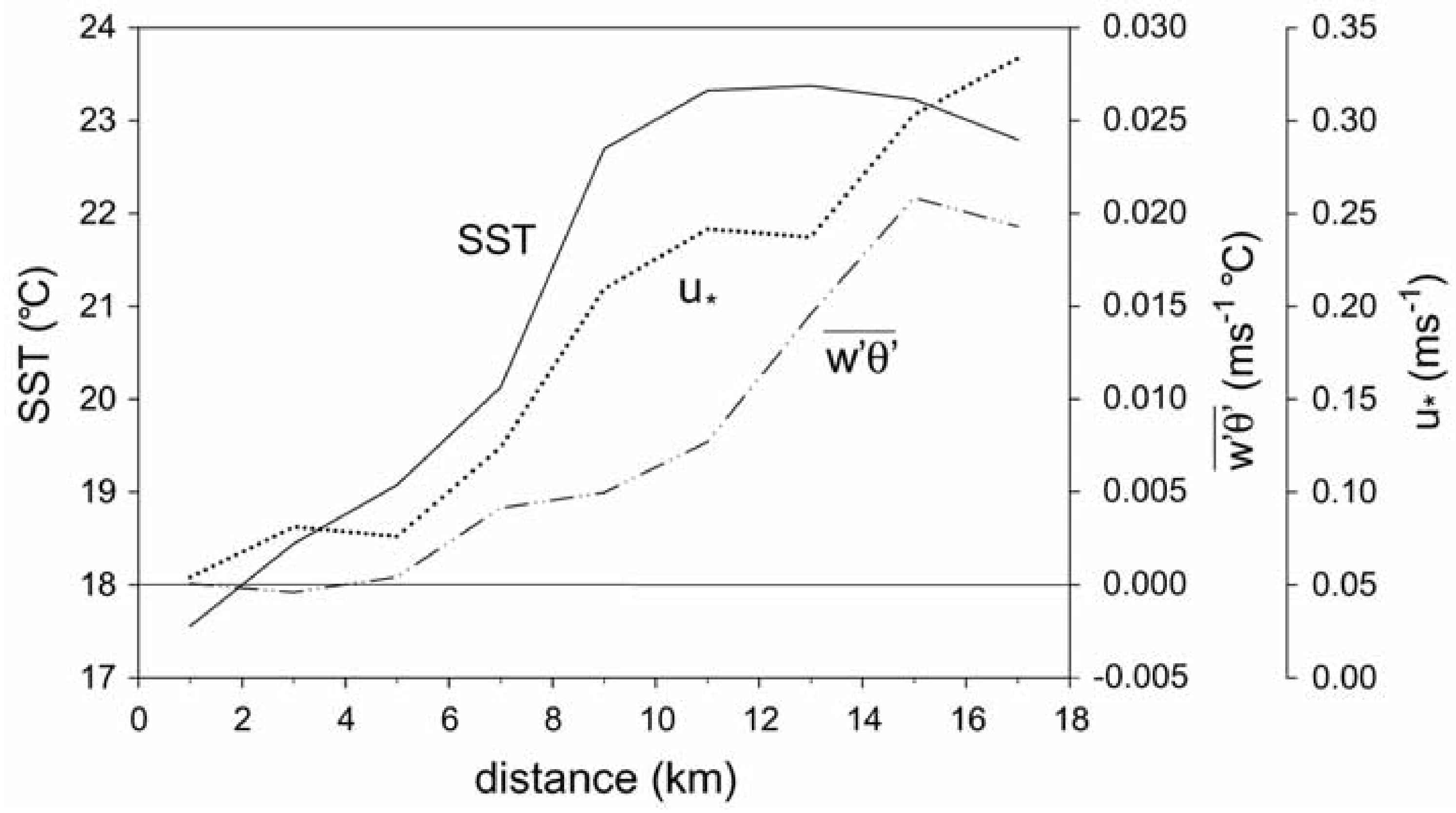
- Black line is the track from Ryan Maue's data set

- Lack of retrieval in areas with too much rain and between swaths



Graphic courtesy of Joel Scott

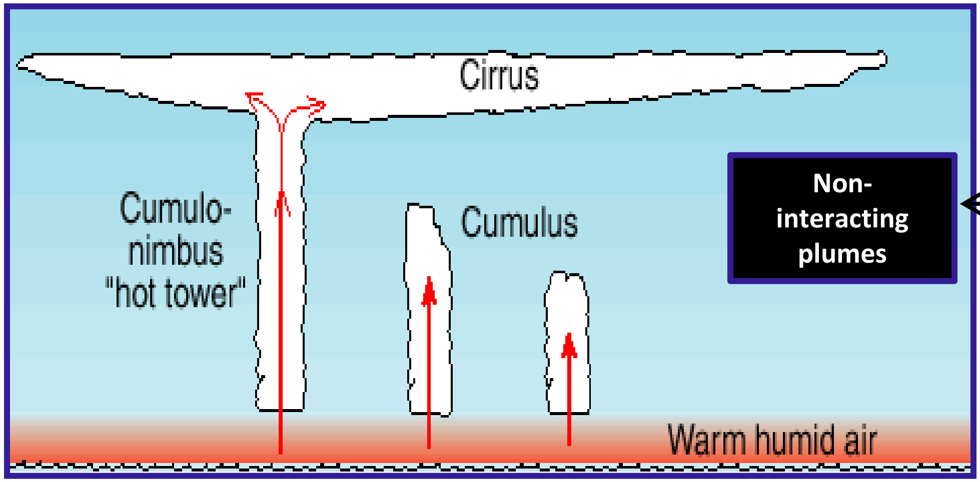
# In situ aircraft measurements over the north wall of the Gulf Stream (flow here from left to right)



u* increases by several times associated with SST increase of ~5°C over ~10 km (flow is from left to right)

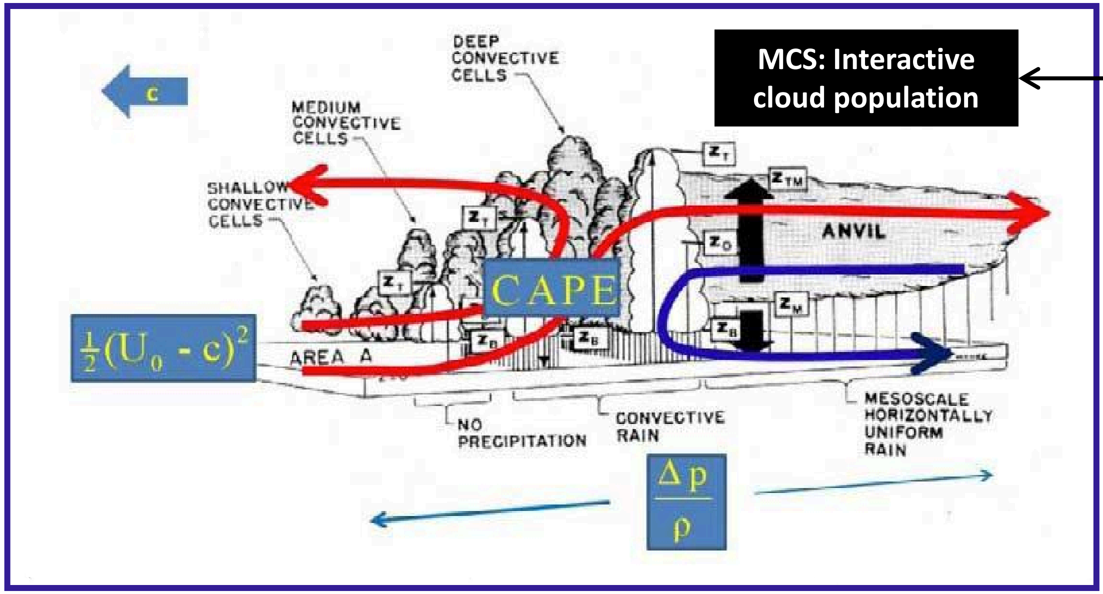
Stress estimated here using direct covariance method

Mahrt et al (2004) BLM



**Non-interacting plumes**

Early view of tropical convection and parameterization, e.g., Arakawa & Schubert (1974)



**MCS: Interactive cloud population**

MCS : missing from climate models -- not parameterized, not resolved

# Mesoscale Convective Systems (MCSs) exist on a wide range of space and time scales

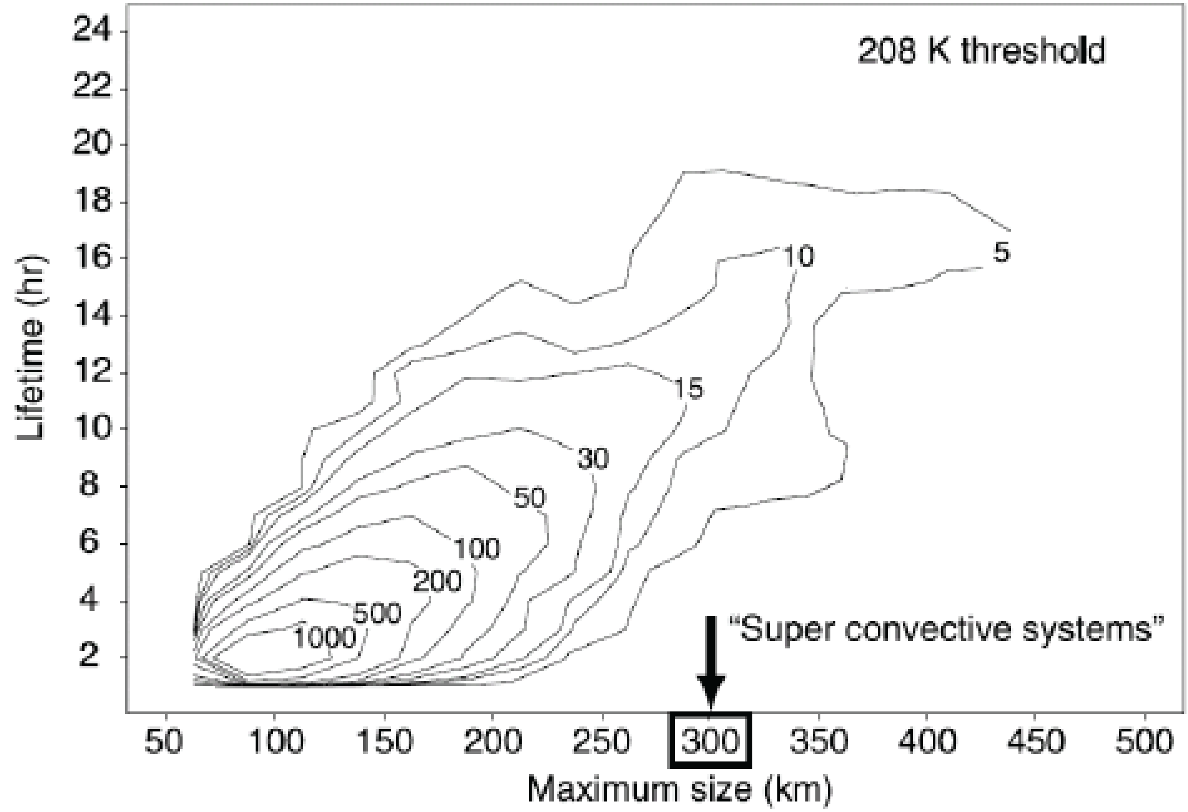
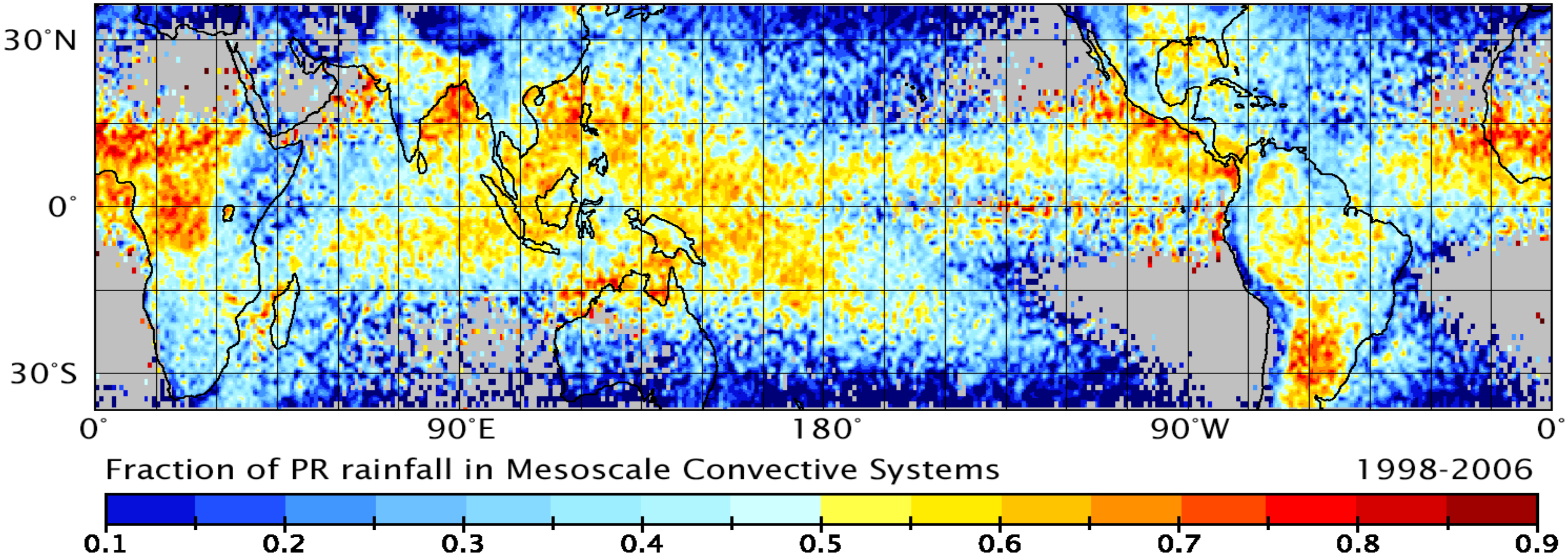


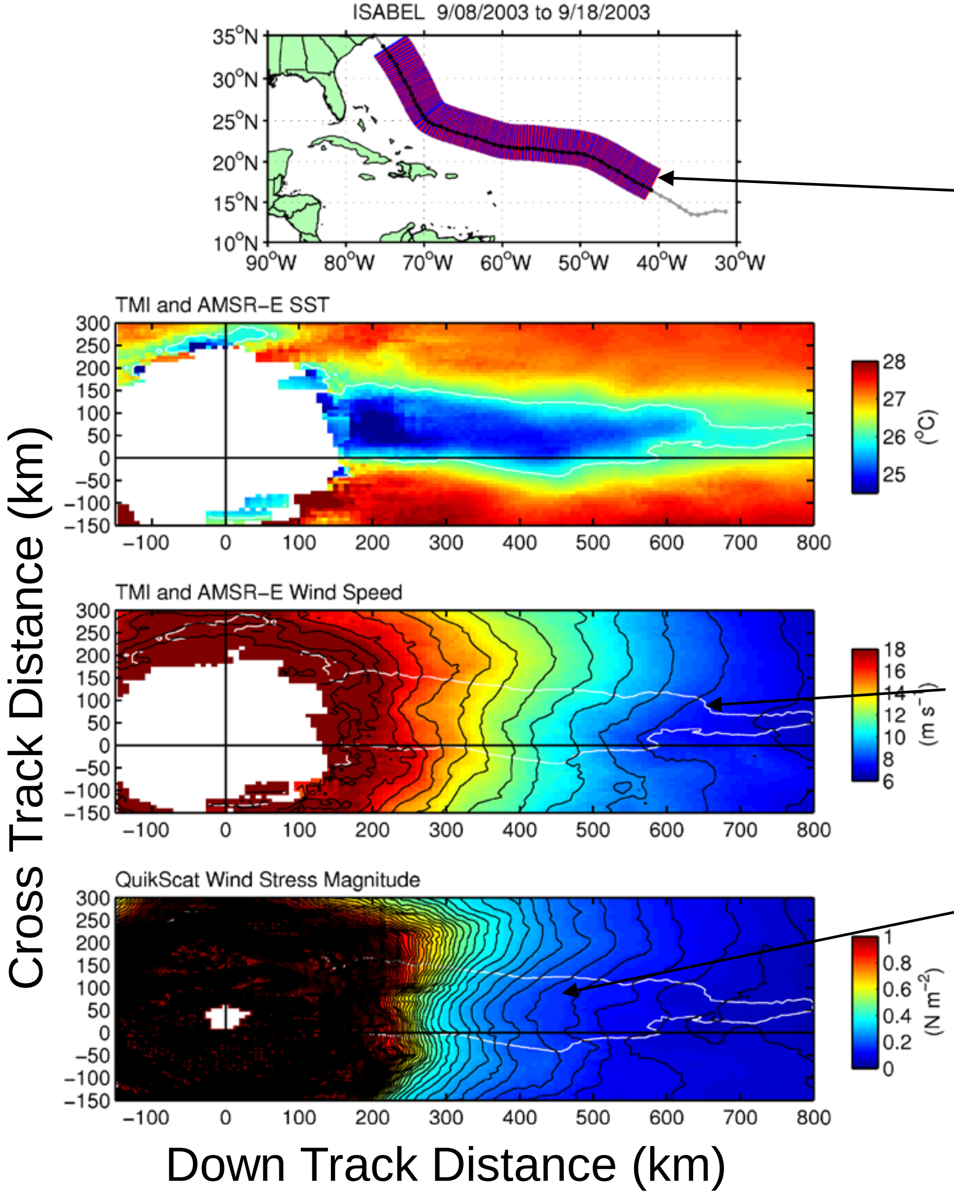
Figure 3.27: Timescales and space scales of MCSs in TOGA COARE. MCSs were defined by a cloud top temperature threshold of 208 K and by whether they exhibited continuity in both space and time. Frequency distribution shows occurrences of tracked MCSs (number per 25-km-size interval per hour) as a function of the maximum size (abscissa) reached by a convective system during its lifetime (from start to end of its life cycle). From Houze (2004).

# MCS: Building blocks of tropical convective organization



Tao and Moncrieff (2009)

# Wind speed and stress reduction in the cold wake of Hurricane Isabel (Sept 2003)



Satellite wind and SST interpolated onto an along and cross track coordinate system (track based on NHC track determination)

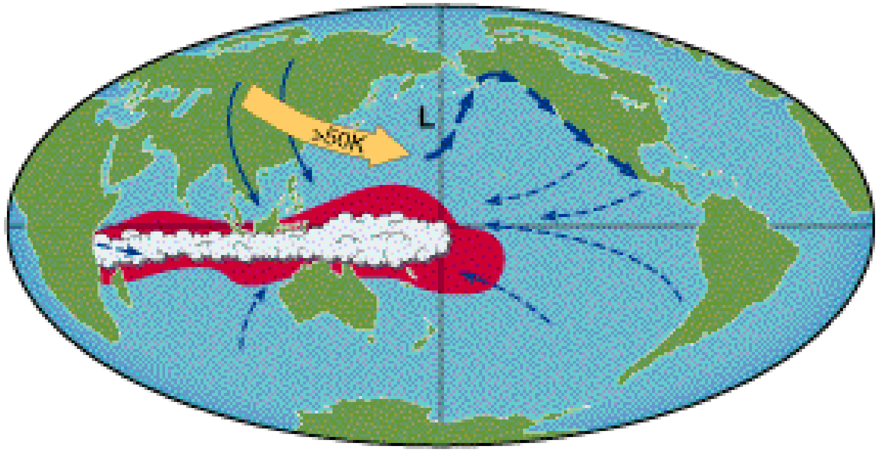
SST is reduced by 2-3°C

26°C isotherm

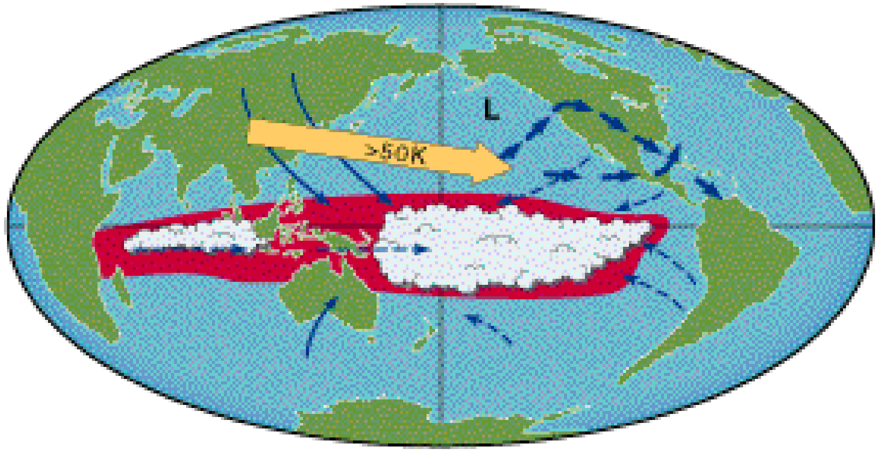
Surface wind stress reduced by 15-30% over the cold wake

From Discussion by Larry O’Neill

# El Niño-Related Changes in Pacific Ocean



Non-El Niño

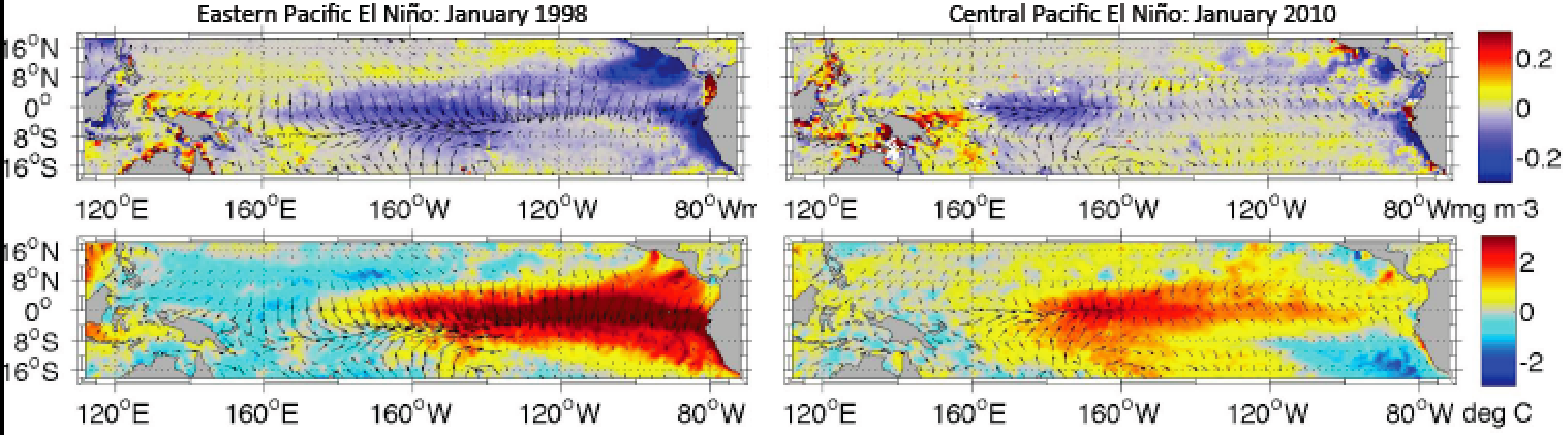


El Niño

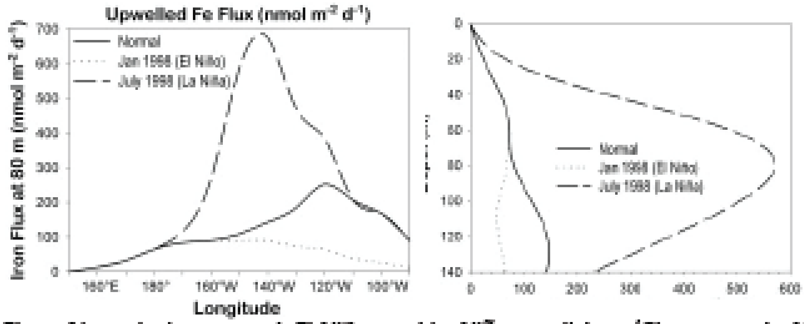
- During El Niño events the warm surface waters and cloud cover move from the eastern Pacific Ocean to the into the central Pacific Ocean.
- The position of the upper level jets (thick blue arrows also changes.
  - Changing the storm track.
  - Changing precipitation rates.
  - Changing temperatures.

# Interannual Biophysical Interaction: ENSO

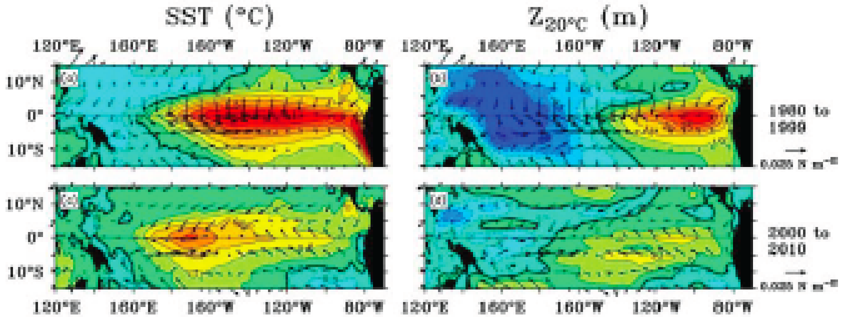
Gierach, Lee, Turk, and McPhaden (GRL, in prep.)



(upper) SST anomaly from Reynolds ¼-degree OISST, and (lower) SeaWiFS chl-a anomaly for the 1997-98 EP-El Niño and 2009-10 CP-El Niño. All images are overlaid with wind vector anomalies from CCMP. Note the high (low) SST and reduced (less reduced/positive patches) chl-a in association with the EP-El Niño (CP-El Niño).



Flux of iron during normal, El Niño, and La Niña conditions (Chavez et al., 1999).



Composites of (a) SST (in °C) and (b) Z20 (in m) for December-February (DJF) of El Niño years during 1980–1999 and 2000-2010 with zonal wind stress (in N/m$^2$) overplotted on both (McPhaden et al., 2011).

ENSO significantly influences weather patterns and ocean circulations, which in turn affect the physical and biological states of the tropical and extratropical Pacific via remote and local forcings (i.e., Rossby waves, Kelvin waves, alterations of the local wind field, alongshore currents, and large-scale ocean gyre circulation).

Biophysical responses differ with respect to ENSO diversity given variability in local and remote atmospheric and oceanic forcing, and the resultant horizontal and vertical processes.

# Multi-Scale Structure

Nakazawa 1988

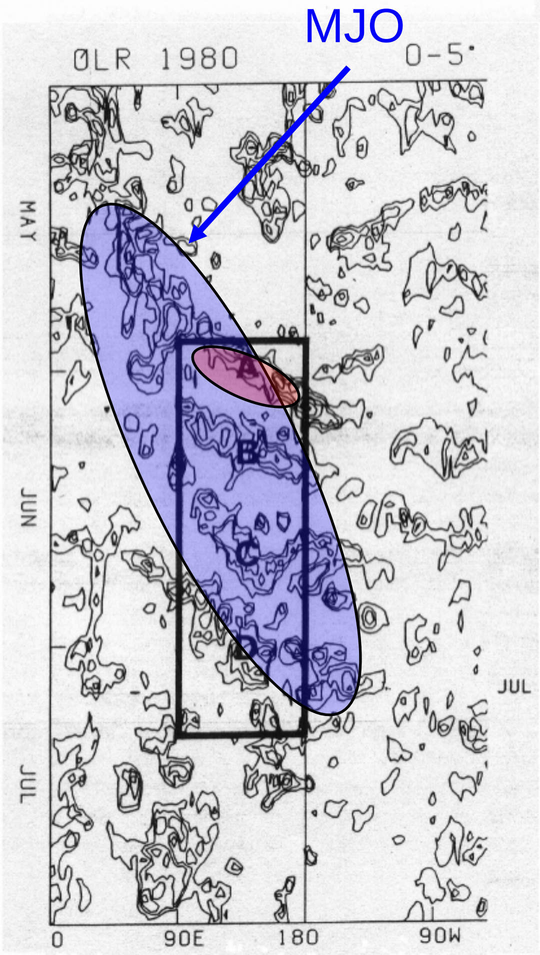


Figure 1

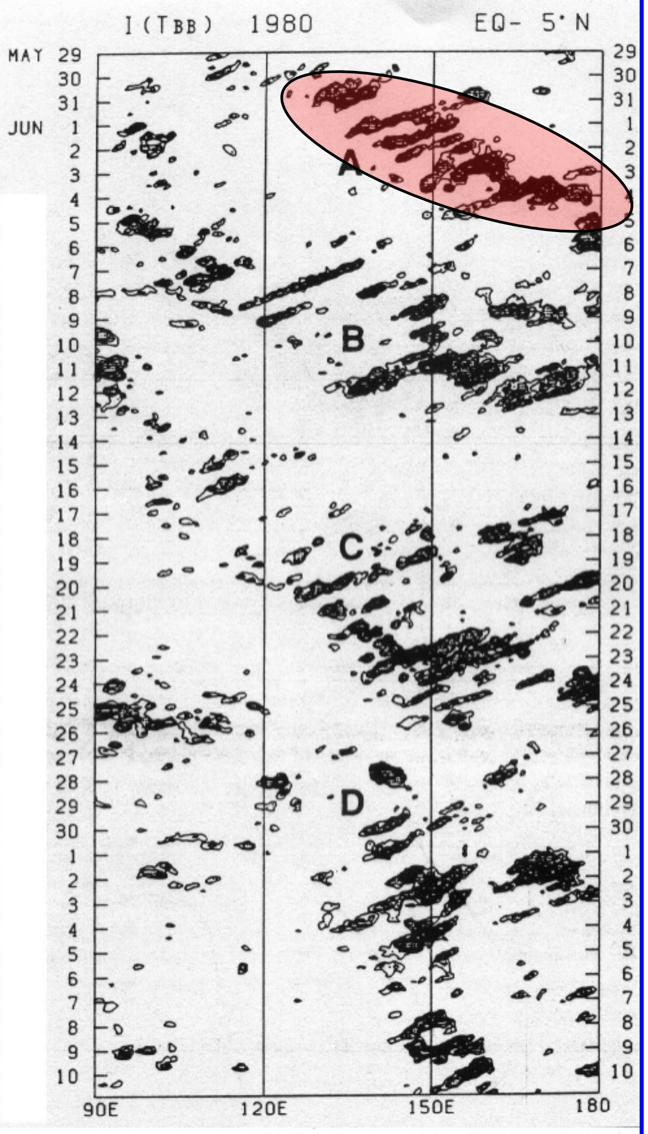


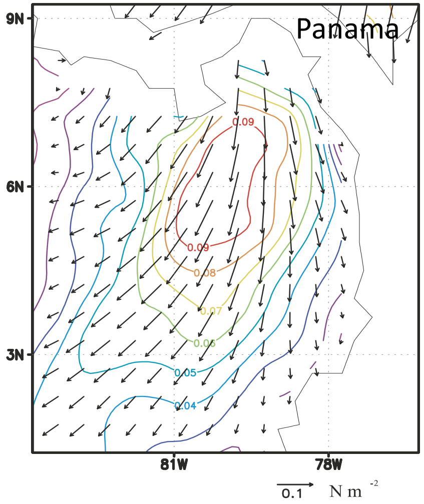
Figure 2

How Important is
This Finer Structure To
The Phase Speed, Eastward
Propagation, etc

Convection input from
Duane Waliser

# Research using ADEOS Ocean Color, SST, and Ocean Winds

NSCAT Wind Stress



OCTS SST

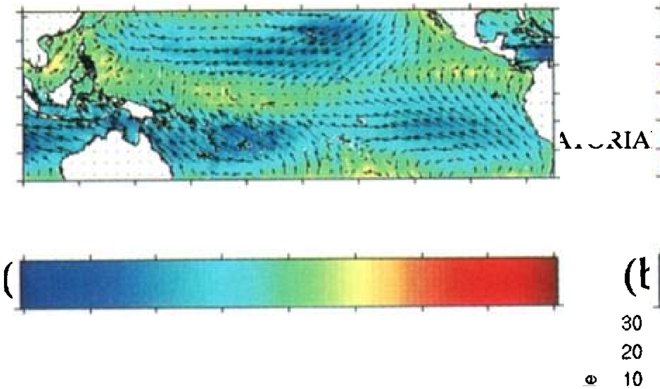
Panama

OCTS Ocean Color

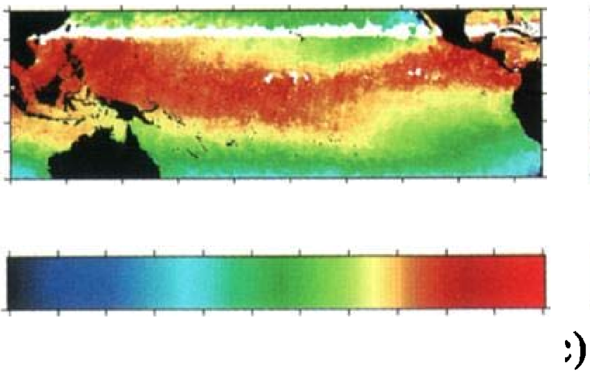
Panama

[image from Rodriguez-Rubio and Stuardo, 2002]

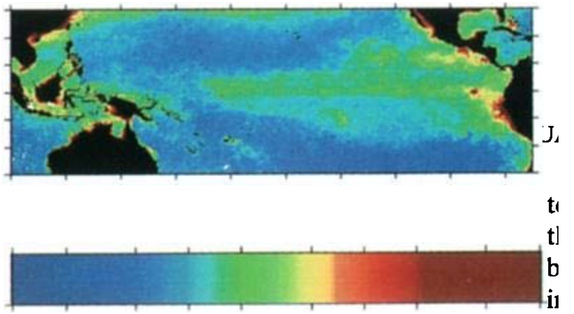
NSCAT Wind Stress



OCTS SST



OCTS Ocean Color



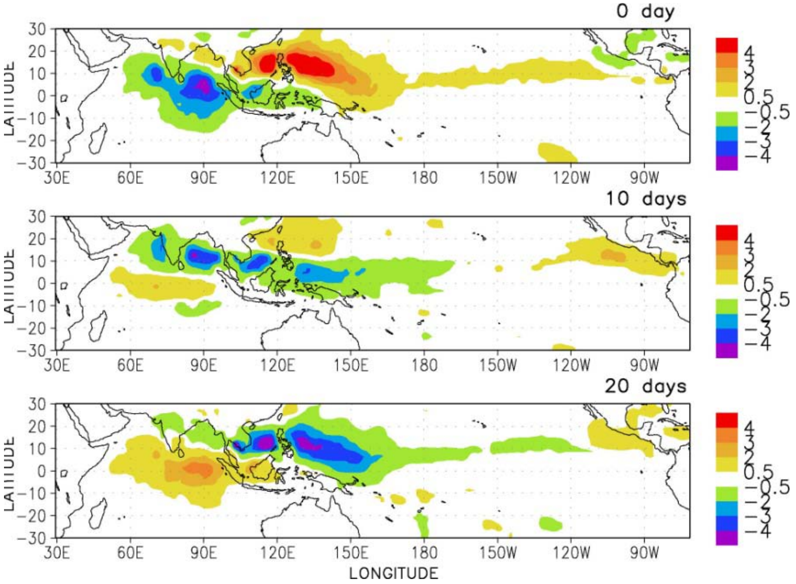
[image from Murakami et al., 2000]

# The MJO and Ocean Chlorophyll:

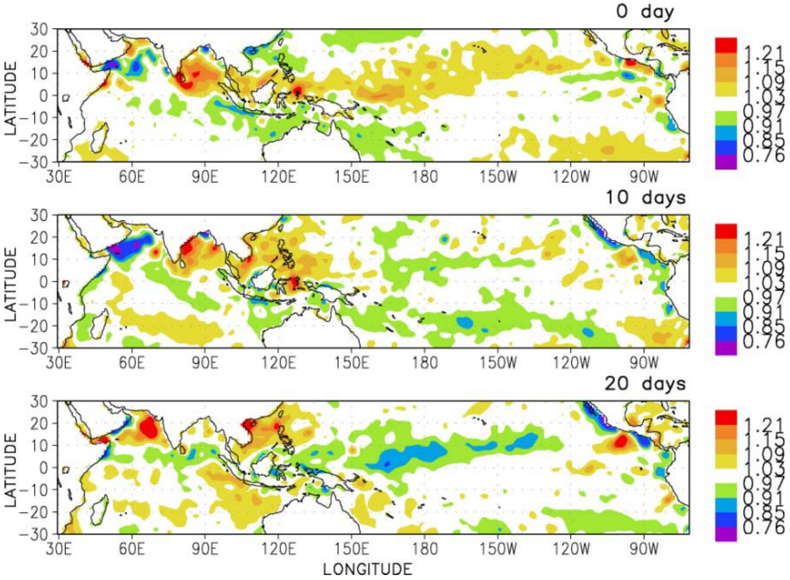
## *Could MJO Predictions Be of Use to the Fishing Industry?*

Waliser (JPL), Murtugudde (UM), Strutton (OSU), Li (JPL), GRL, 2005

MJO Rainfall Variations: NH Summer

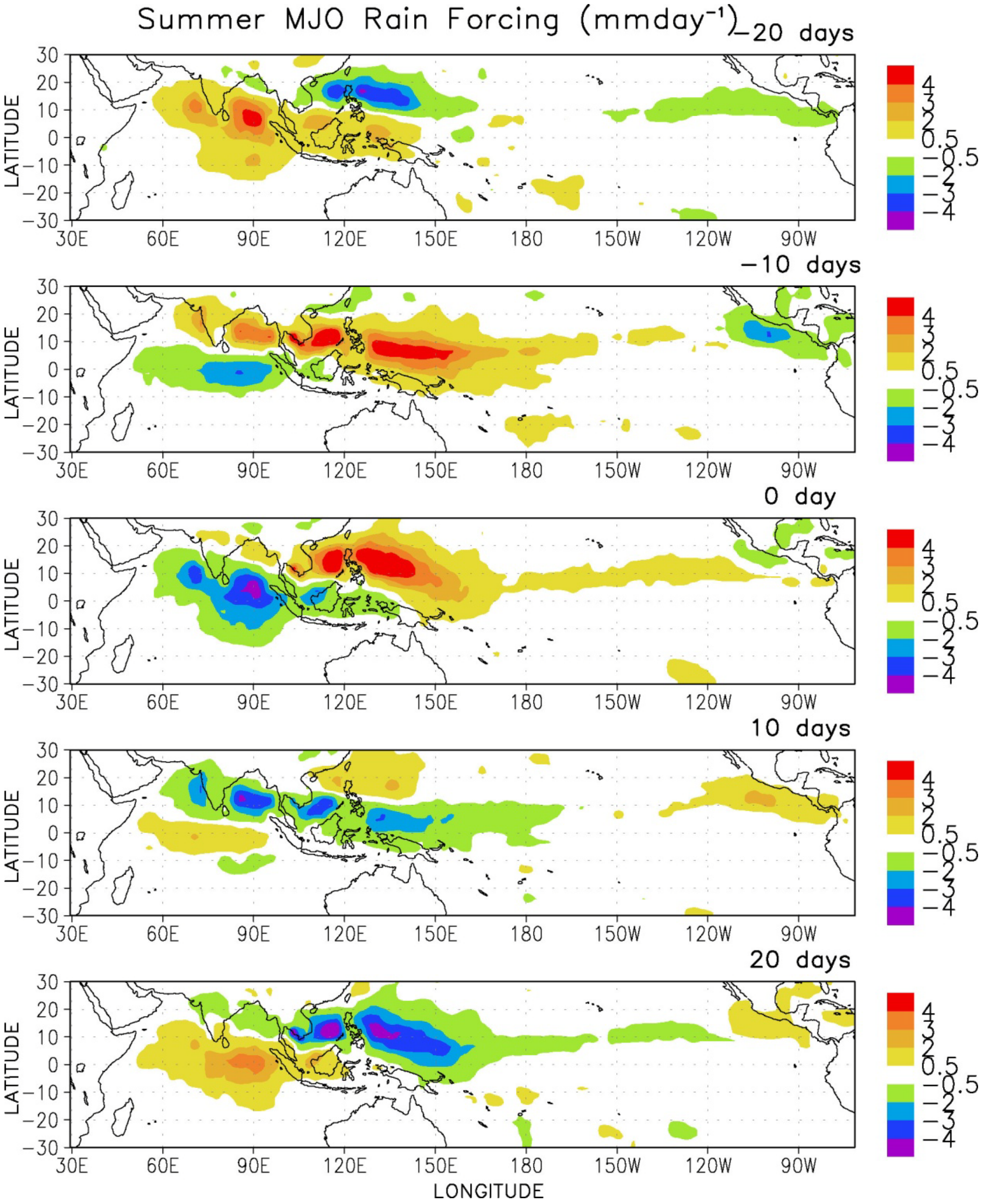


Associated Fractional Change in Chl



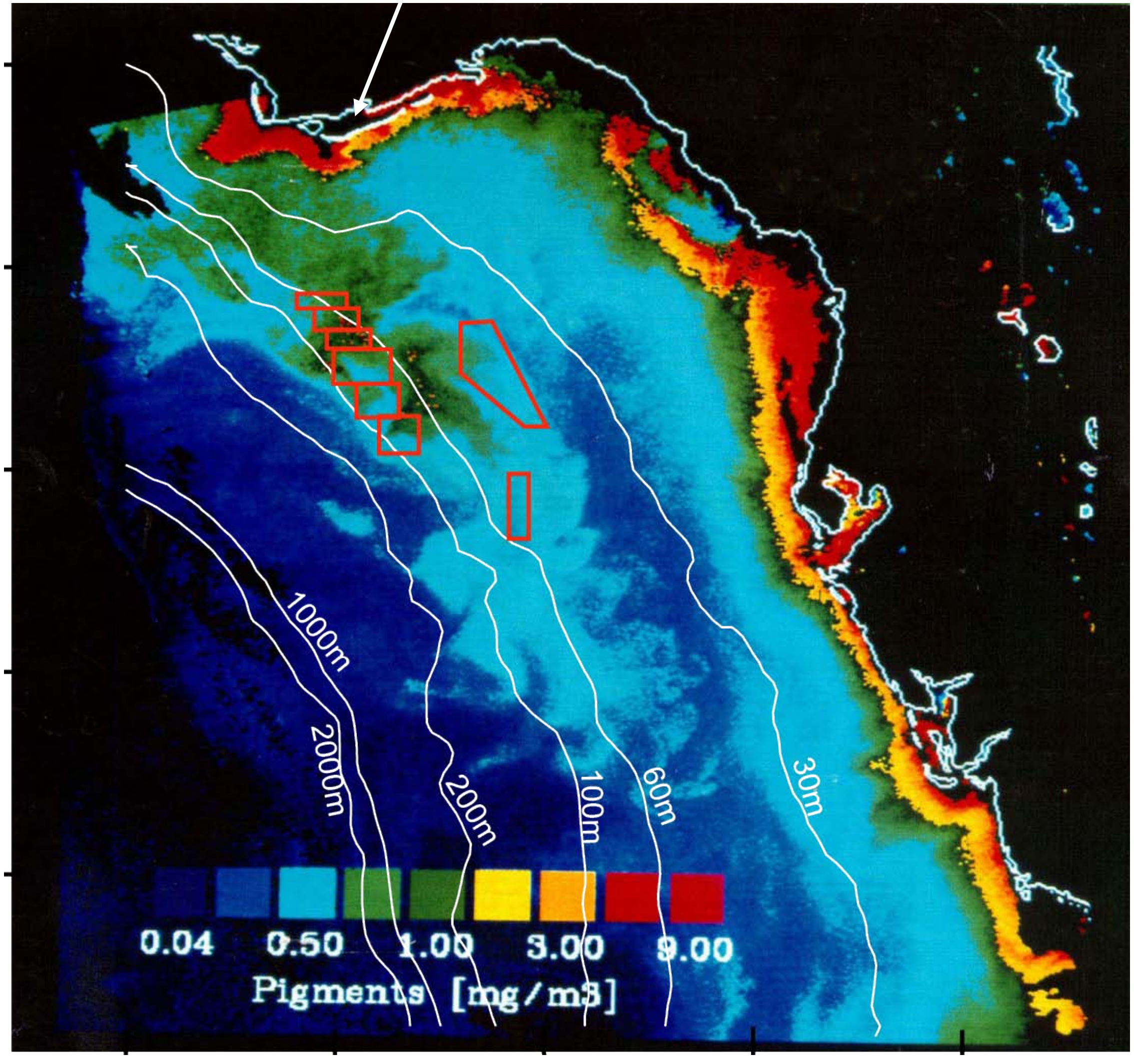
- *The MJO has systematic and significant influence on Chl concentrations over a widespread regions of the Tropical Oceans.*
- *Preliminary analysis indicate that wind-induced vertical mixing of nutrients may be in part responsible for the Chl changes.*

- *This result, along with the indication that the MJO is predictable with lead times of 2-3 weeks, imply that large-scale changes in Chl might also be predictable at these lead times which is likely to be a valuable asset to the ocean fishing industry.*



# RAINFALL COMPOSITE N.H. SUMMER

- *Maps are separated by 10 days.*
- *Rainfall anomalies propagate in a northeast fashion and mainly affect the Tropical eastern hemisphere.*
- *These anomalies are accompanied by anomalies in wind, solar radiation, sea surface temperature, etc.*
- *Rain and water vapor are important players in radiative fluxes*



*Apalachicola Bay*

Satellite imagery suggests high chlorophyll concentrations found over known spawning habitats of gag grouper during the late winter/early spring spawning months may be linked with the Apalachicola River.
  - Indicated by red boxes

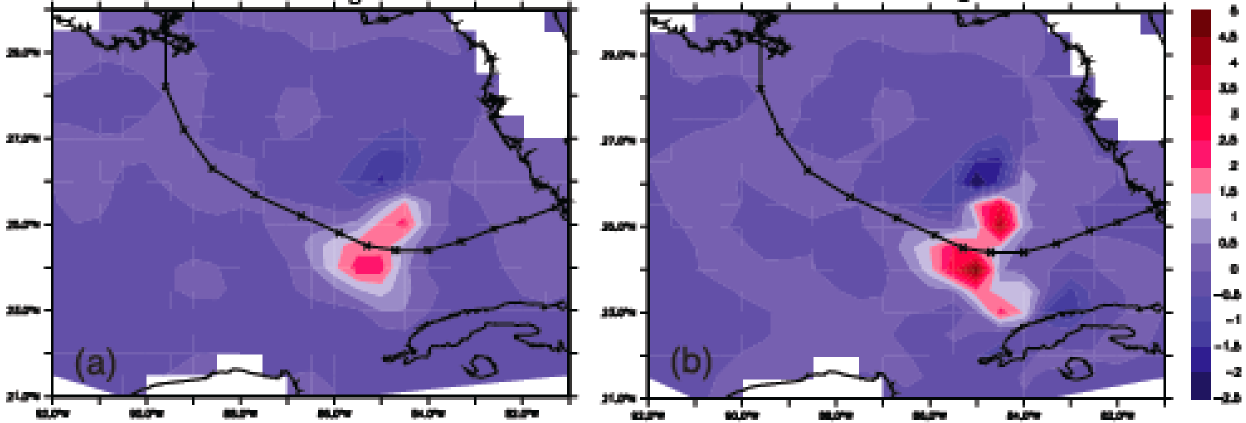
This tongue of greater chlorophyll concentrations is due to river outflow and the passage of atmospheric fronts and other strong weather systems.
  - it is not due to mean winds

Graphic courtesy of
Steve Morey

# Synoptic Biophysical Interaction: Hurricanes

Gierach and Subrahmanyam (JGR, 2008)

Wind-driven QuikSCAT-derived Upwelling/Downwelling



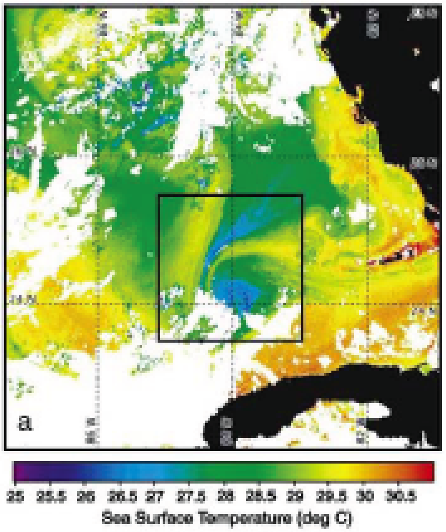
0600 UTC 27 August 2005

1200 UTC 27 August 2005

Ekman pumping ($10^{-4}$ m/s) during passage of Hurricane Katrina (2005) (black line)

AVHRR SST

0317 UTC 31 August 2005

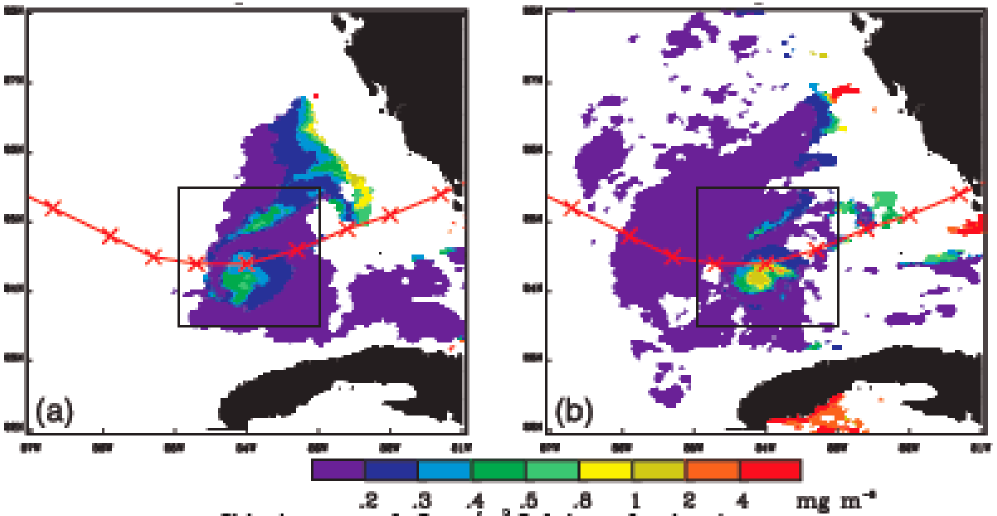


3-4°C SST decrease 4 days after hurricane passage

MODIS Aqua Chlorophyll-a

30 August 2005

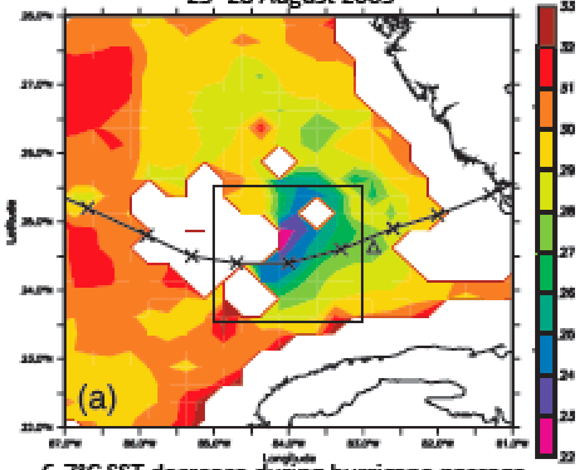
31 August 2005



Chl-a increase of ~3 mg/m³ 3-4 days after hurricane passage

TMI SST

25–28 August 2005

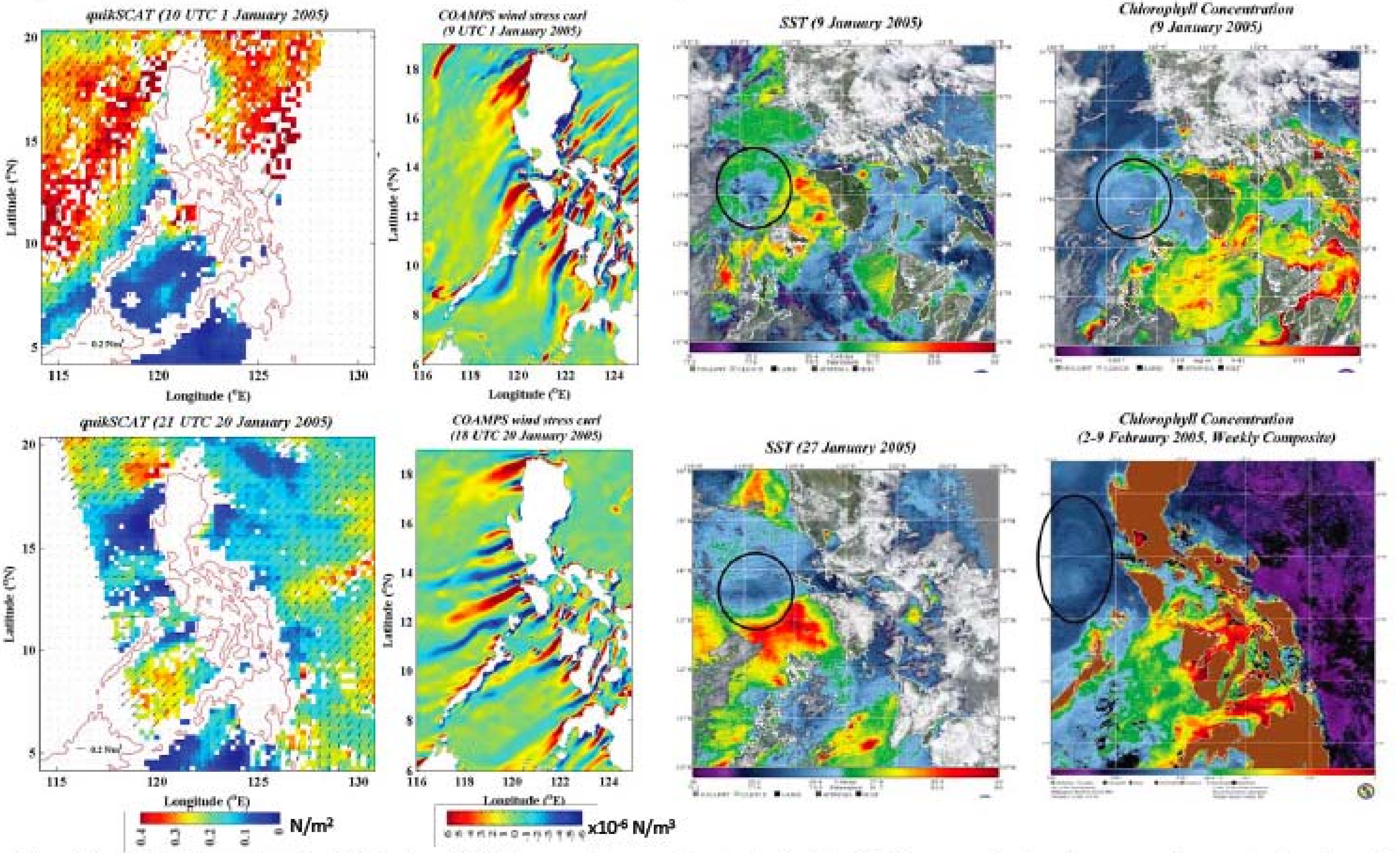


6-7°C SST decrease during hurricane passage

Strong wind-driven mixing and wind-induced upwelling are the mechanisms that control biophysical responses in the vertical water column, such as sea surface cooling and chl-a enhancement. Hurricane-force winds deepen the mixed layer allowing cold, nutrient-rich subsurface water access to the upper water column.

# Seasonal Biophysical Interaction: Monsoon

Pullen et al. (GRL, 2008)



quikSCAT (10 UTC 1 January 2005)

COAMPS wind stress curl (9 UTC 1 January 2005)

SST (9 January 2005)

Chlorophyll Concentration (9 January 2005)

quikSCAT (21 UTC 20 January 2005)

COAMPS wind stress curl (18 UTC 20 January 2005)

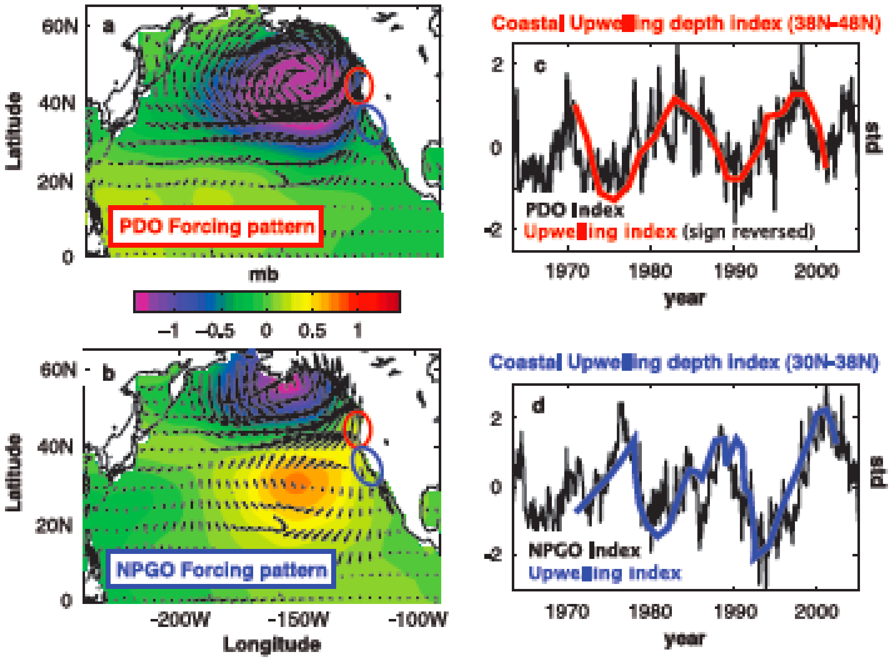
SST (27 January 2005)

Chlorophyll Concentration (2-9 February 2005, Weekly Composite)

Intensified wind jets and wakes in the lee of Mindoro and Luzon Islands during the NE Monsoon induce the generation and migration of counter-rotating oceanic eddy pairs and influence the biophysical state of the South China Sea. Ultimately the wind-driven eddies serve as conveyors of momentum, heat, mass, and biochemical properties.

# Decadal Biophysical Interaction: Pacific Decadal Oscillation (PDO) and North Pacific Gyre Oscillation (NPGO)

DiLorenzo et al. (GRL, 2008)



Atmospheric forcing patterns of the PDO and NPGO modulate decadal changes in coastal upwelling.

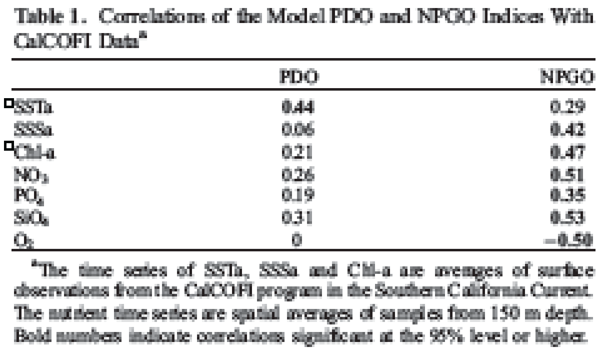
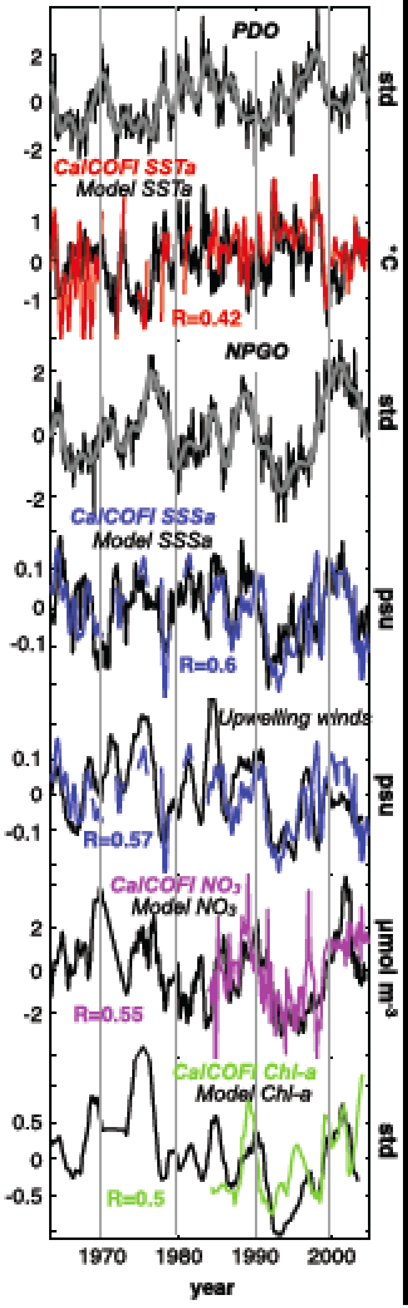


Table 1. Correlations of the Model PDO and NPGO Indices With CalCOFI Data[a]

| | PDO | NPGO |
|---|---|---|
| SSTa | **0.44** | 0.29 |
| SSSa | 0.06 | **0.42** |
| Chl-a | 0.21 | **0.47** |
| $NO_3$ | 0.26 | **0.51** |
| $PO_4$ | 0.19 | **0.35** |
| $SiO_4$ | 0.31 | **0.53** |
| $O_2$ | 0 | **−0.50** |

[a] The time series of SSTa, SSSa and Chl-a are averages of surface observations from the CalCOFI program in the Southern California Current. The nutrient time series are spatial averages of samples from 150 m depth. Bold numbers indicate correlations significant at the 95% level or higher.

Correlation of the NPGO index with *in-situ* nutrient and chlorophyll-a measurements off the coast of southern California indicate that fluctuations in phytoplankton biomass are primarily affected by wind-driven vertical advection.



A positive/cold NPGO increases transport in the Alaskan Coastal Current and California Current and the associated changes in wind forcing create (downwelling-) upwelling-favorable conditions in the (Alaskan Coastal Current) California Current and (Subtropical Gyre) Alaskan.

The strong correlation between upwelling variability off the northeast Pacific coast and the NPGO is only applicable south of 38°N, whereas north of 38°N vertical advection is correlated with the PDO. Therefore, the NPGO can be considered a primary indicator of upwelling strength, nutrient fluxes, and ecosystem changes south of 38°N, and the PDO as an indicator north of 38°N.

# Summary of Science Thoughts for Possible Future NASA Missions, Part I

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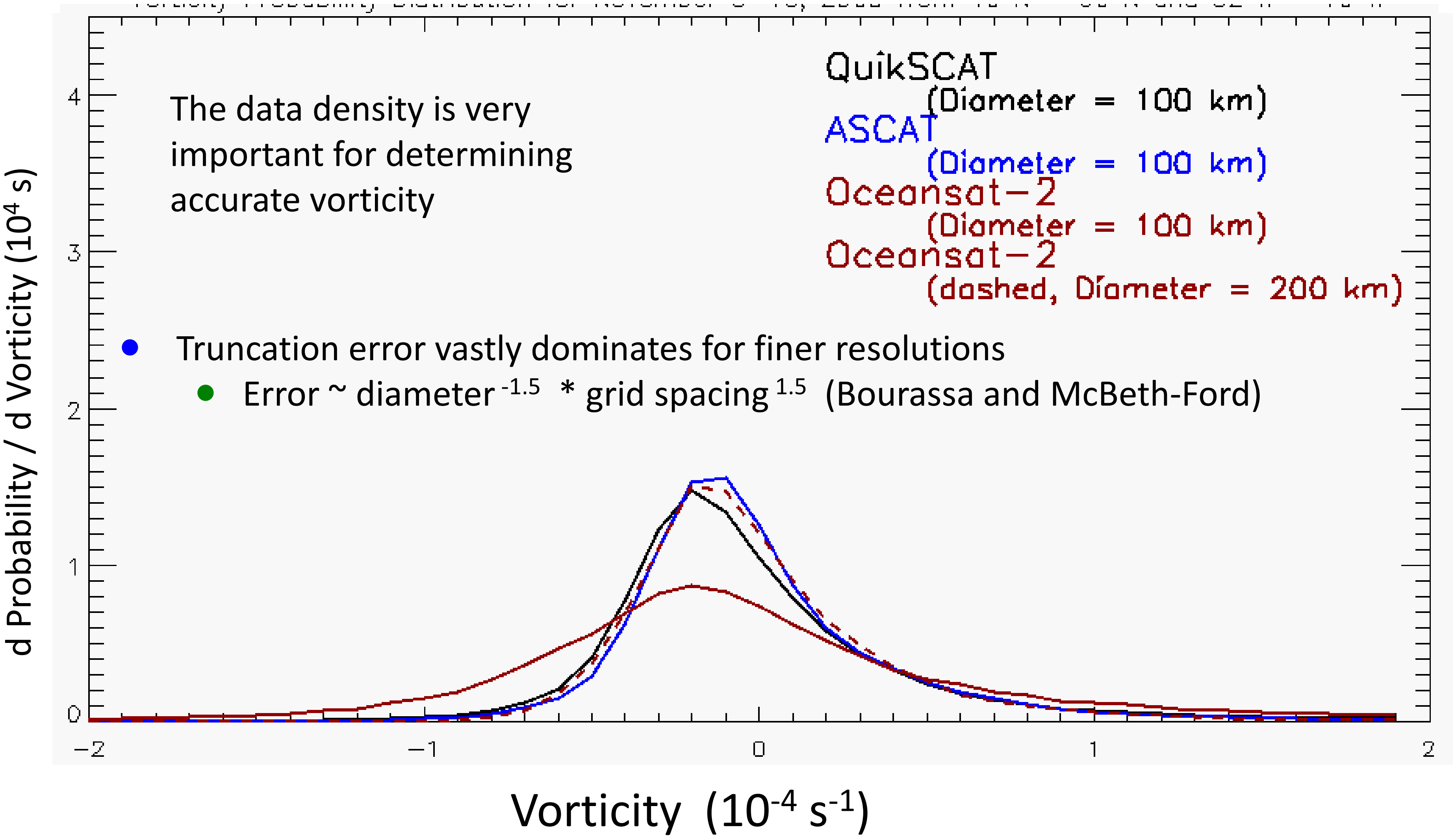
# Probability Density of Vorticity (Atlantic, 40-60N)



The data density is very important for determining accurate vorticity

- Truncation error vastly dominates for finer resolutions
  - Error ~ diameter $^{-1.5}$ * grid spacing $^{1.5}$ (Bourassa and McBeth-Ford)

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