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# Testing turbulence theory using satellite measured ocean winds

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*The problem:*

- *The structure of atmospheric turbulence in the mesoscales (2 – 2000 km)*
- *The scales of most severe weather*
  - *meso-gamma (~2 – 20 km)*

    *… convection*
  - *meso-beta (~20 – 200 km)*

    *… mesoscale convective systems, squall lines*
  - *meso-alpha (~200 – 2000 km)*

    *… tropical cyclones*

*Importance:*

- *Improve weather and climate models*
- *Test hypotheses on physical mechanisms*
- *Aid development of theory*

*The reference model is*

- *Homogeneous, isotropic, divergence-free, 2D turbulence, forced at small and large scales.*
- *Theory predicts an energy distribution that scales as*

$$\text{small scales: } k^{-5/3} \qquad (r^{2/3})$$
$$\text{large scales: } k^{-3} \qquad (r^{2})$$

- *In 2D turbulence: energy is transferred upscale*
- *What about the real atmosphere?*

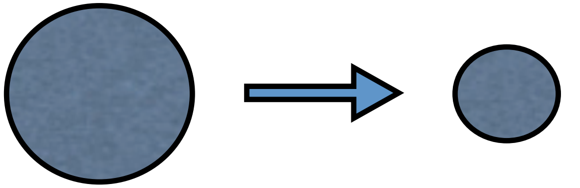
## ***An Ongoing Debate…***

## ***is Atmospheric KE transferred…***

*Down-scale?*

*(as in 3D turbulence)*

Large eddies to small eddies

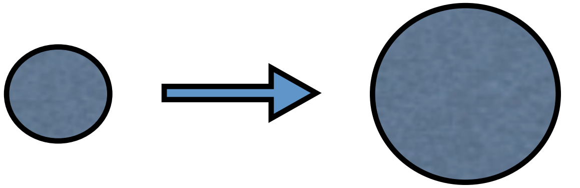


*OR*

*Up-scale?*

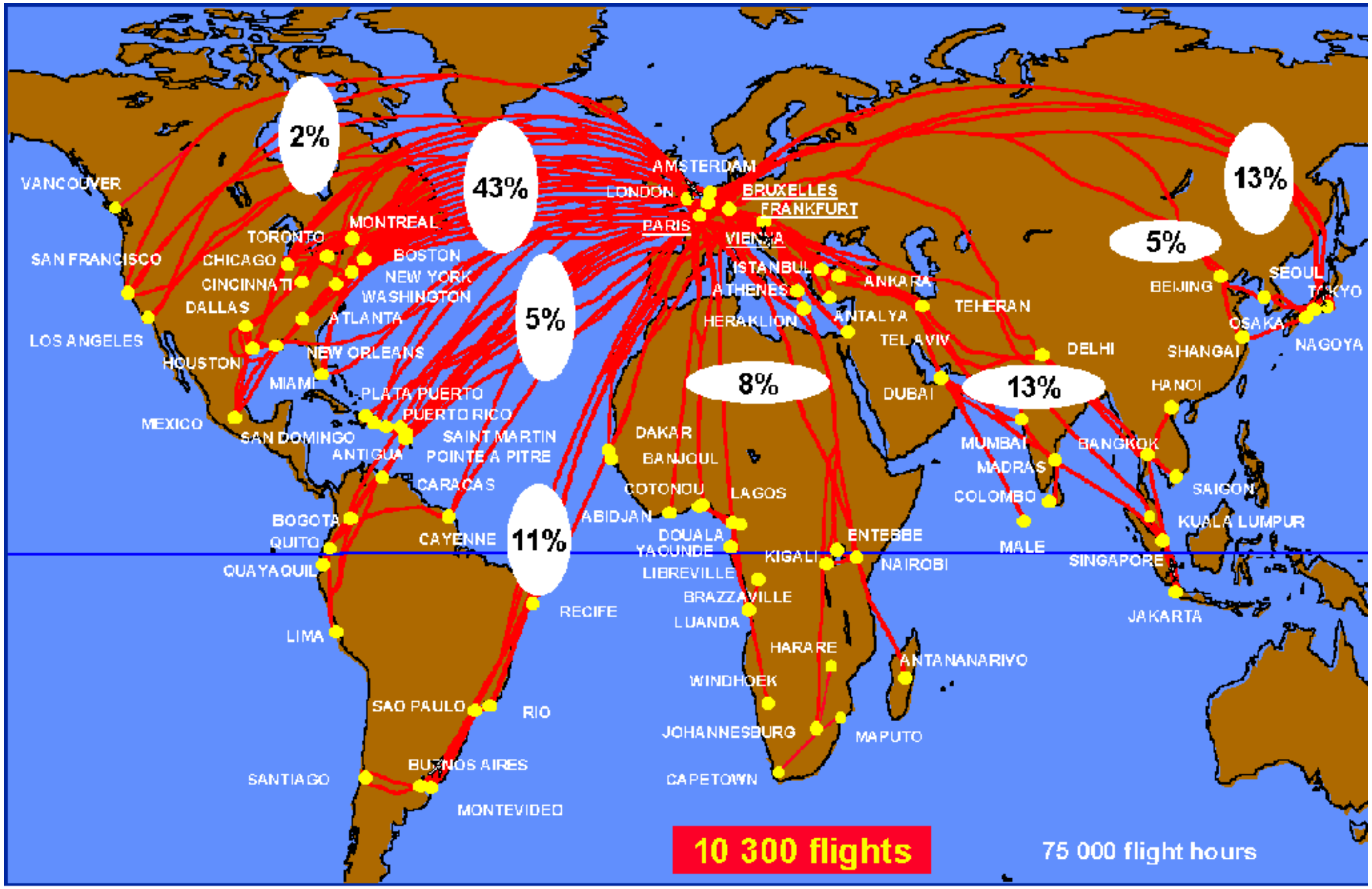
*(as in 2D turbulence)*

Small eddies to large eddies



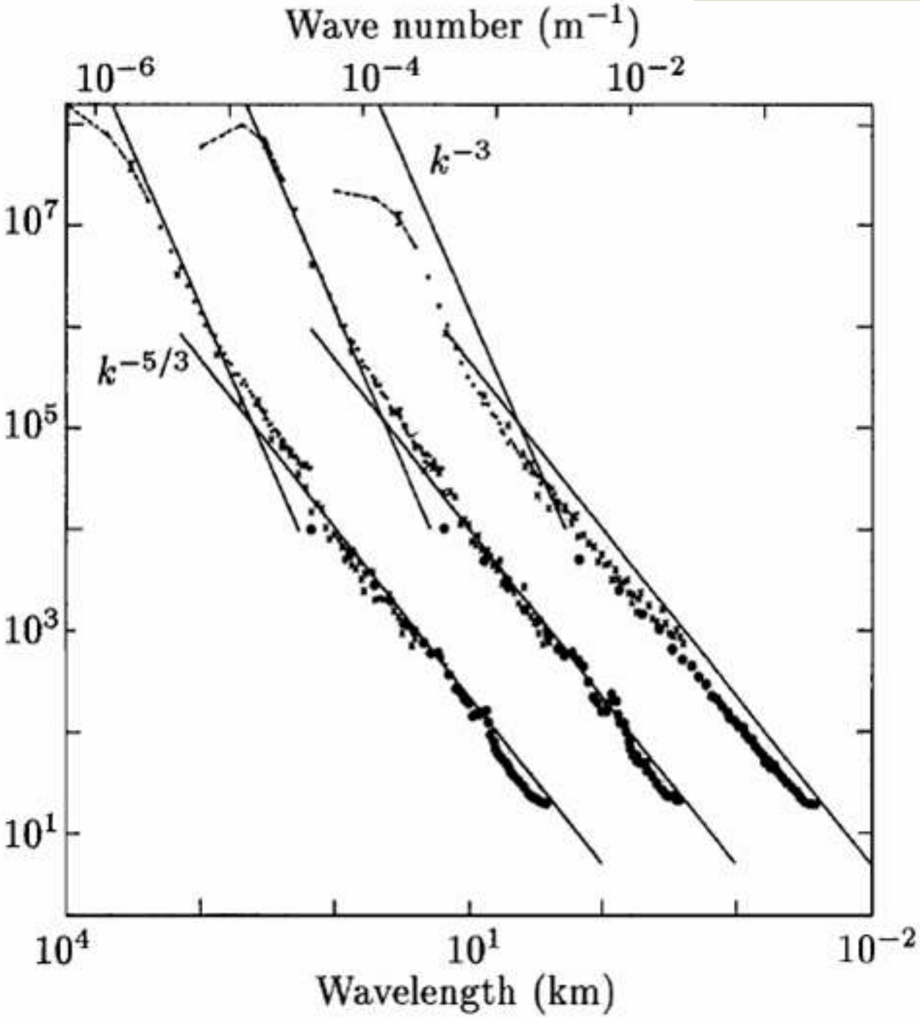
# Observations

## Instruments on commercial aircraft



# Upper Troposphere Winds

Nastrom et al (1984)




***Main Hypotheses…***

***k*** $^{-3}$ : Geostrophic turbulence
(Charney, 1971)

***k*** $^{-5/3}$ :

- Stratified Turbulence with upscale cascade
  (Gage 1979, Lilly 1983)
- Gravity Waves (downscale)
  (Dewan 1979; VanZandt 1982)
- Stratified Turbulence with downscale cascade
  (Lindborg, 2006)

# *Satellite Winds*

**Scatterometer winds…**

- At the bottom of the marine boundary layer

ASCAT-on-MetOp-A (swath grid)

- ASCAT-12.5 (12.5 km)
- ASCAT-25 (25 km)

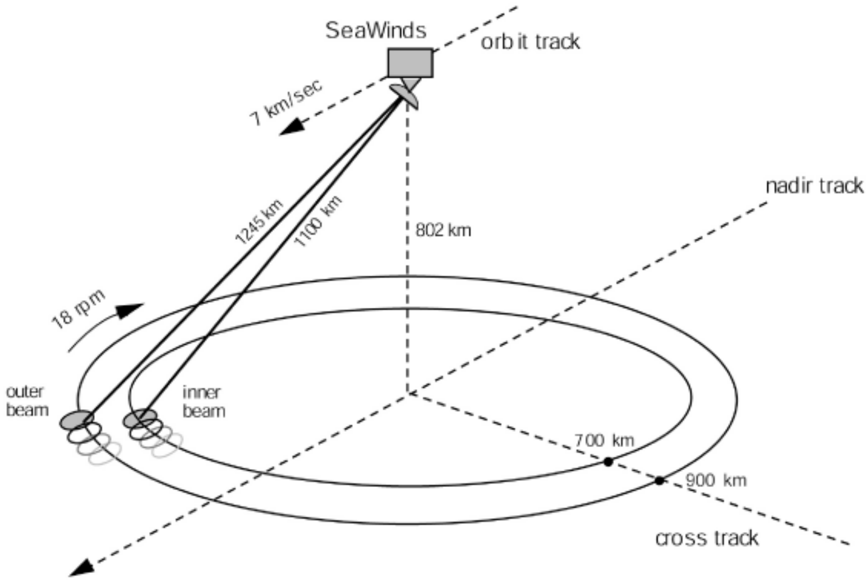
SeaWinds-on-QuikSCAT

- SeaWinds-KNMI (25 km)
- SeaWinds-NOAA (25 km)

KNMI == Royal Netherland Meteorological Institute

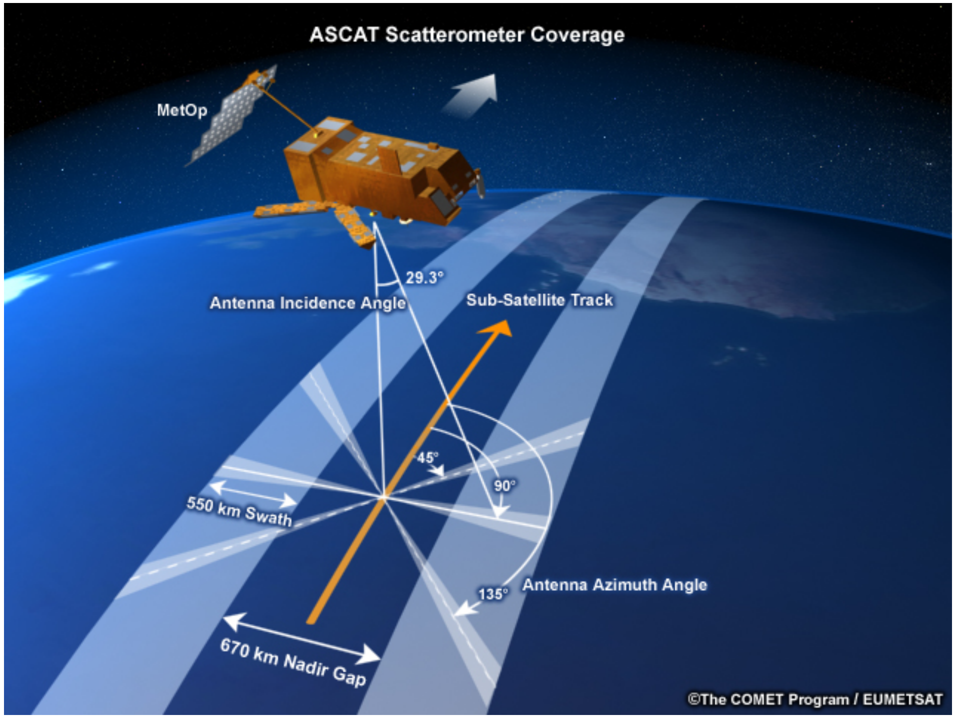
**SeaWinds**

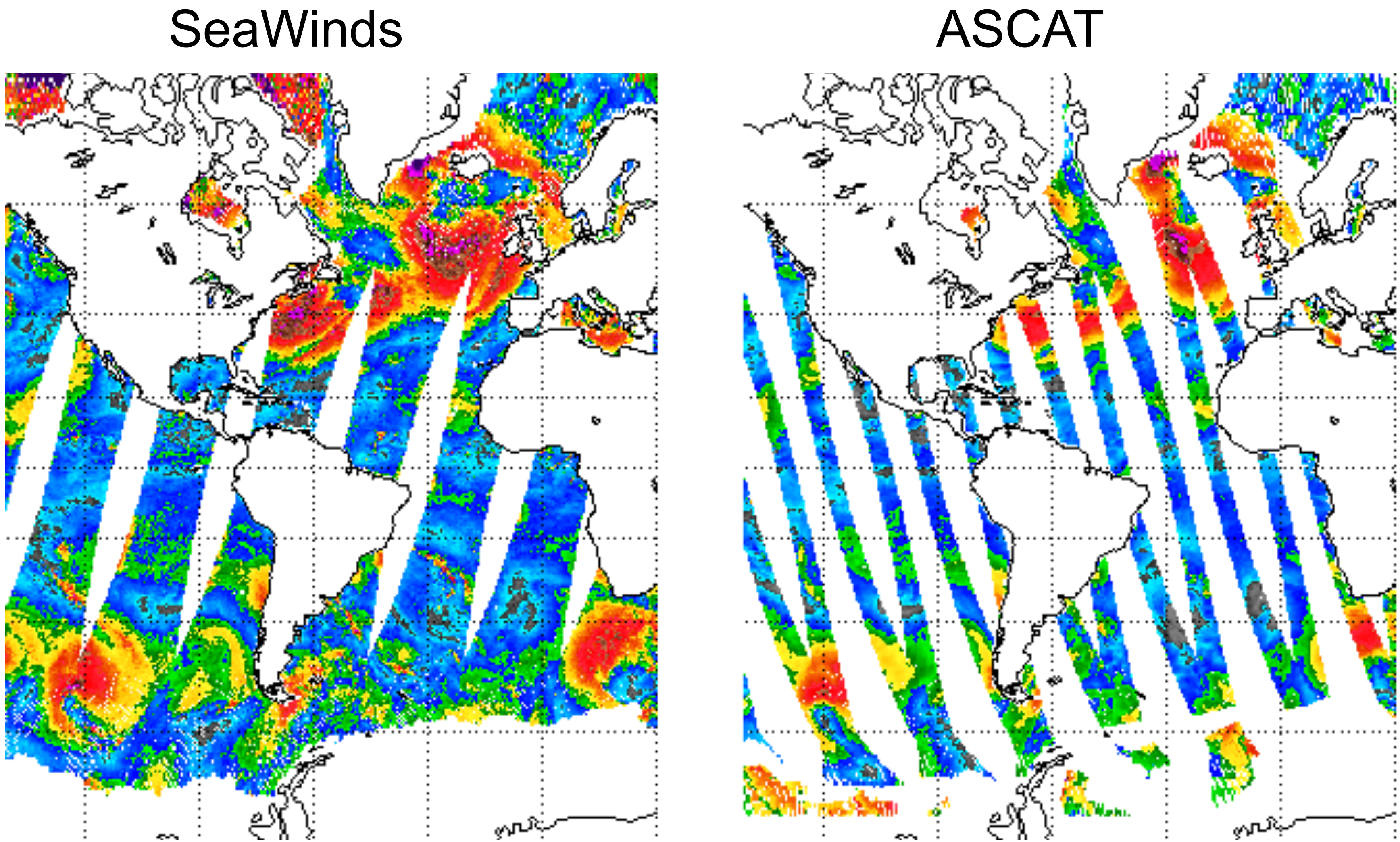
- Ku-band
- ~2 cm
- 13.4 GHz
- Wind vectors degraded by rain
- Complicated geometry
- But no nadir gap (1800 km wide swath)




**ASCAT**

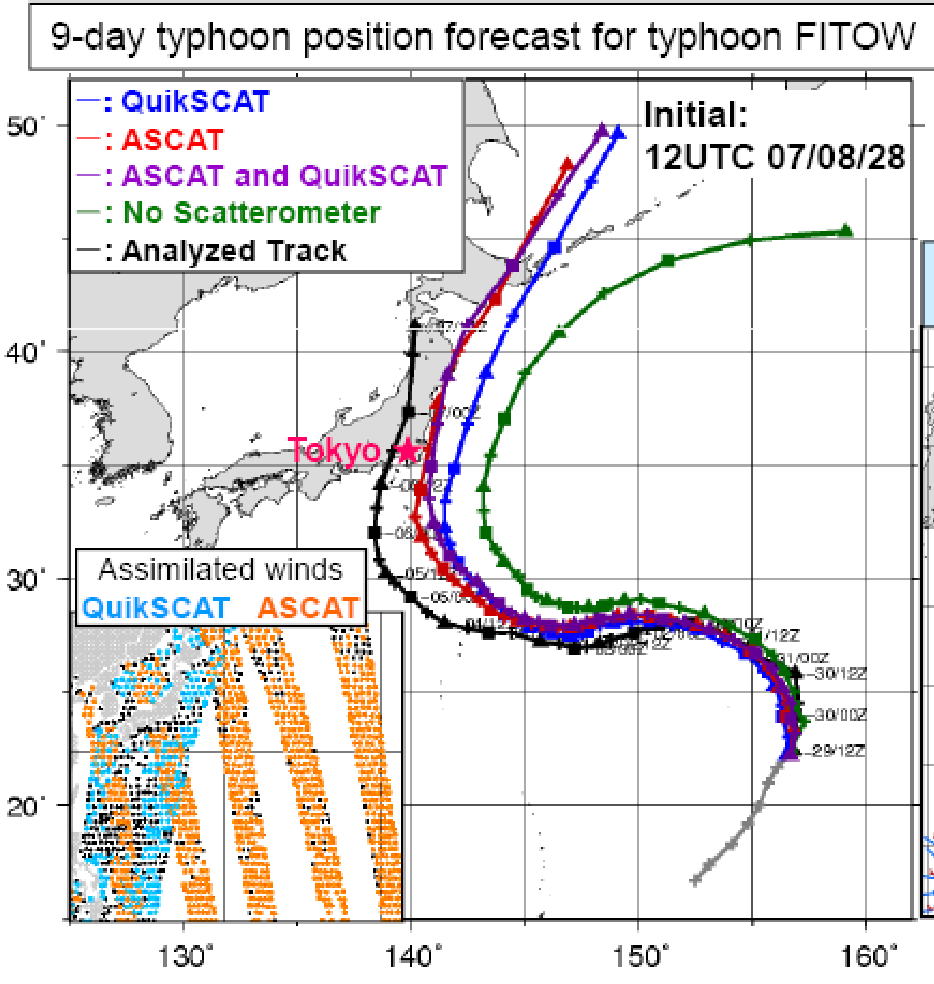
- C-band
- ~5 cm
- 5 GHz
- Unaffected by rain !
- Simple geometry
- Has nadir gap






Due to the nadir gap, it might seem that ASCAT misses important information about large storms.  However …

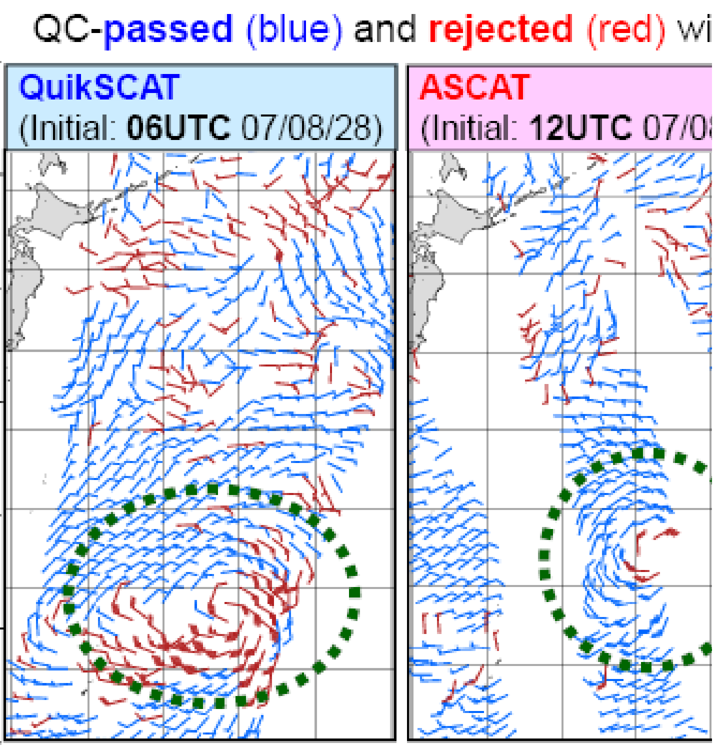
# Typhoon track





Masaya Takahashi[1] and Yoshihiko Tahara
Japan Meteorological Agency

NASA Ocean Vector Wind Science Team Meet
Seattle, 19-21 November 2008

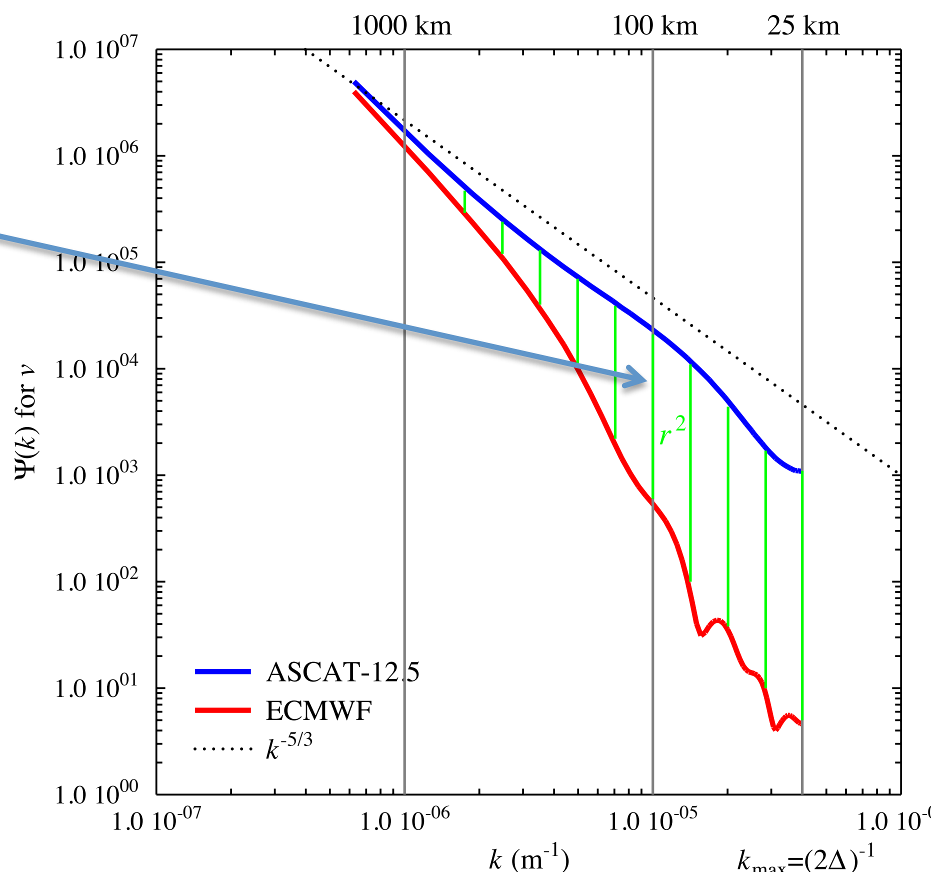


# On the quality of high-resolution scatterometer winds

Vogelzang et al JGR 2011

## Observation error

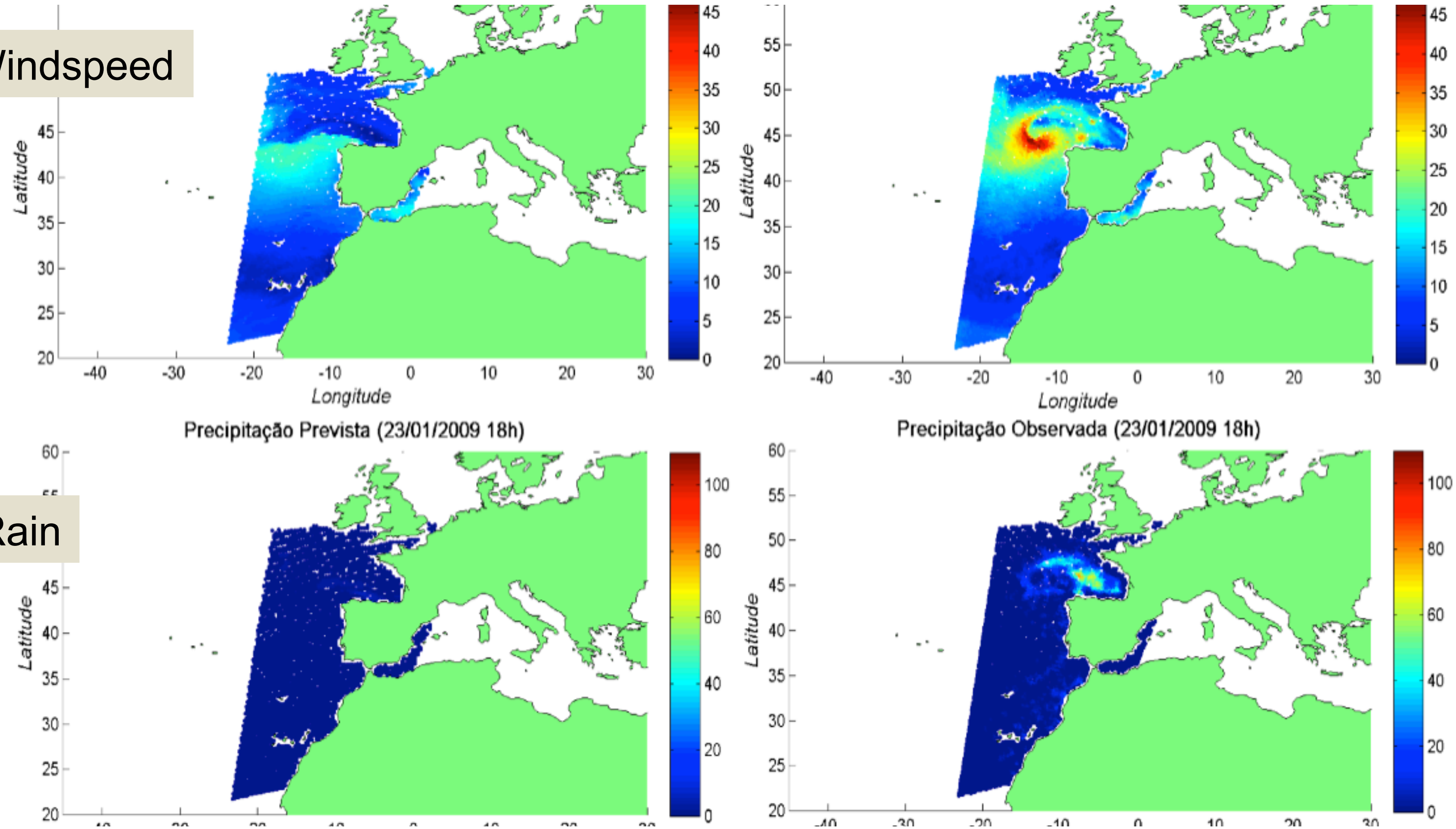
Representation Error



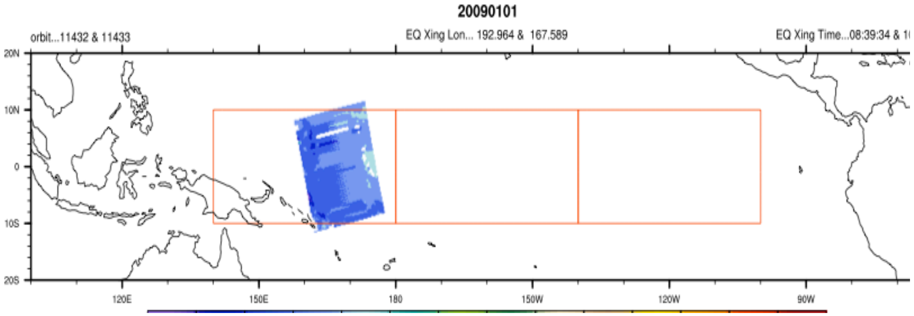
# NWP SeaWinds

Windspeed

Rain



# *Study Area*

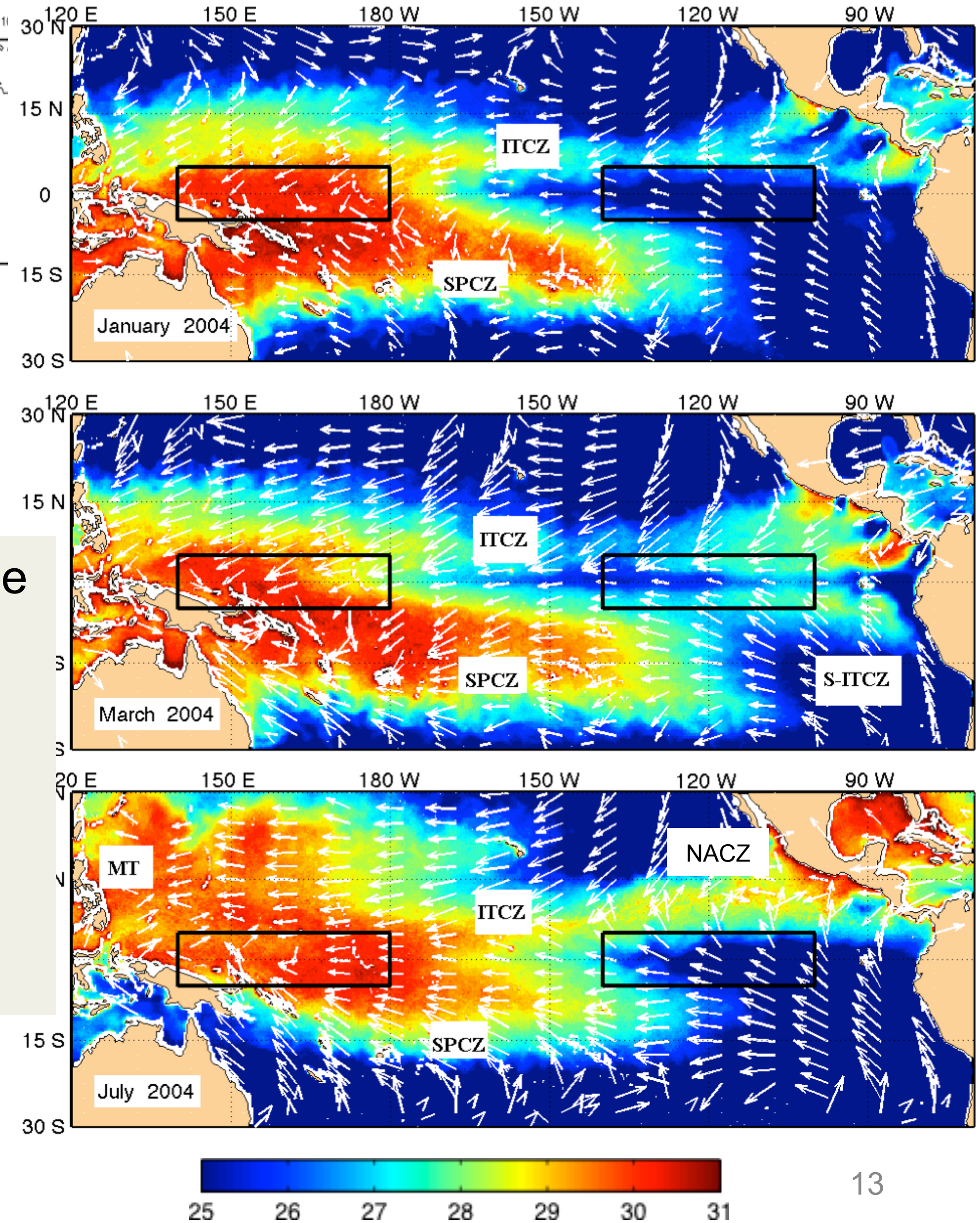



18 deg latitude = 1600 km
64 grid points at 25 km
128 grid points at 12.5 km

ITCZ: Inter-Tropical Convergence Zone
S-ITCZ: Southern ITCZ
SPCZ: South Pacific CZ
NACZ: North American CZ
MT: Monsoon Trough

West Pacific Warm Pool
East Pacific Warm Pool

# **SST and Winds**



# Organized Tropical Convection

During austral summer
(SPCZ active season)

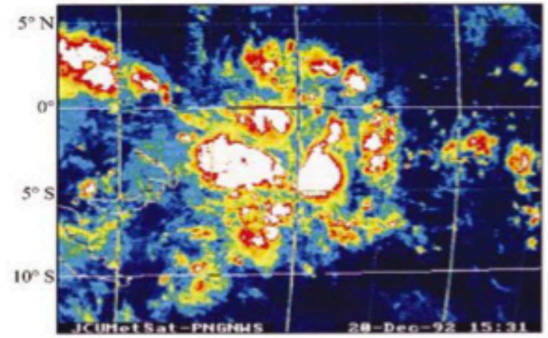



**Figure 1.1** Mesoscale convective clusters embedded within a Supercluster, observed from space on 20th December 2003 during TOGA COARE. Mesoscale systems as white (cold) cloud tops observed by a geostationary satellite. (Source: Moncrieff, 2003, pp 1526)

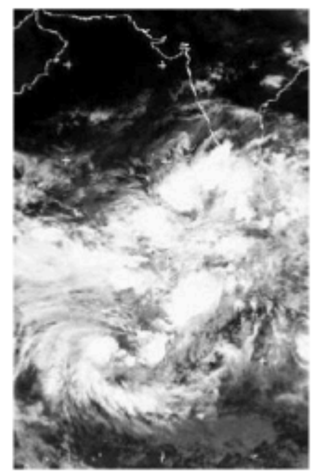
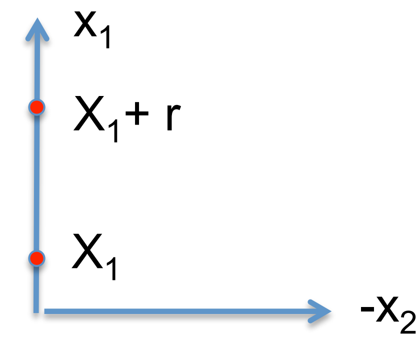


**Figure 1.2** Supercluster over the Indian Ocean, with Tropical cyclone formation in the bottom left hand corner of the Infrared satellite image. May 2nd 2002, 1800 UTC (Source: MTMG19 Tropical Convection Module).

The term Supercluster was first used by Nakazawa (1988) to describe large regions of organized tropical convection, with diameters of the order 1000km and lifetimes generally more than 2 days. They can act as triggers for tropical cyclone formation as seen in figure 1.2 in the bottom left hand corner.

# Methods

» Correlation functions of **velocity differences**




- along-swath analysis ($x_1$)
- velocity components
  - (along-swath, cross-swath)
  - $(u_1 , u_2)$
- velocity differences

$$\delta u_1 = u_1(x_1+r) - u_1(x_1)$$
$$\delta u_2 = u_2(x_1+r) - u_2(x_1)$$

$\delta u_1^2 \sim$ || divergence $||^2$

$\delta u_2^2 \sim$ || vorticity $||^2$

- Structure functions

2nd order

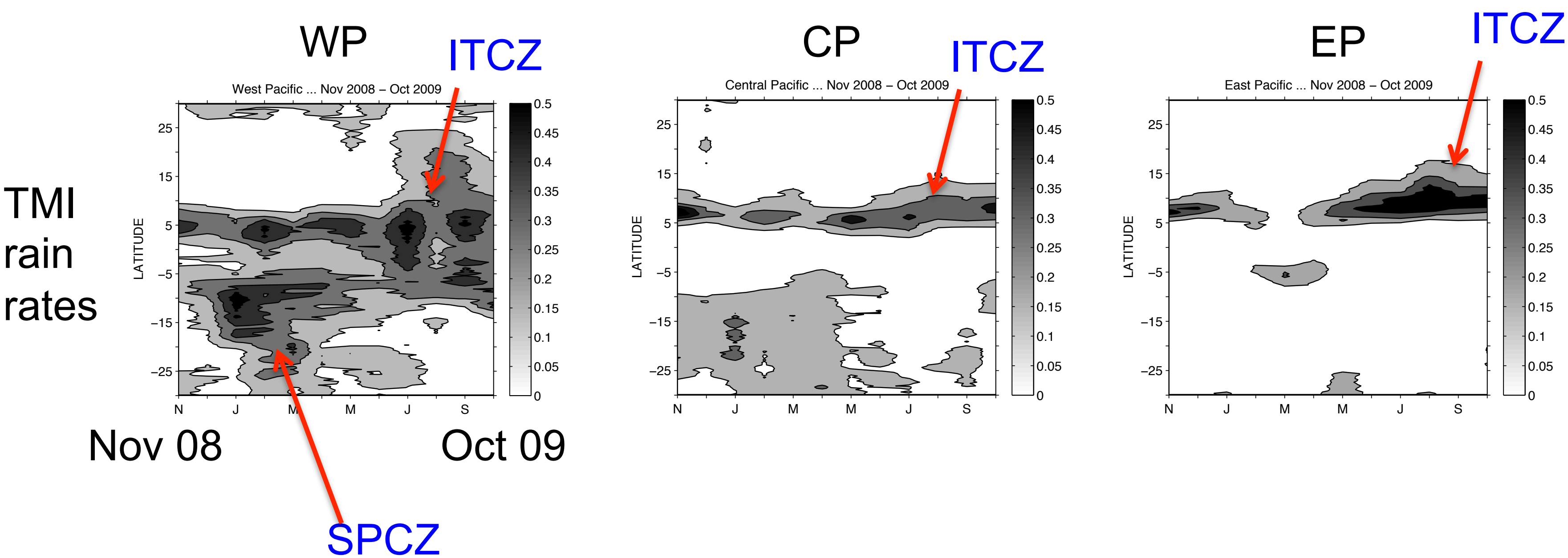
$$D_{11a} = \langle \delta u_1 \delta u_1 \rangle$$
$$D_{22a} = \langle \delta u_2 \delta u_2 \rangle$$

3rd order

$$D_{3a} = \langle \delta u_1 (\delta \vec{u} \cdot \delta \vec{u}) \rangle$$

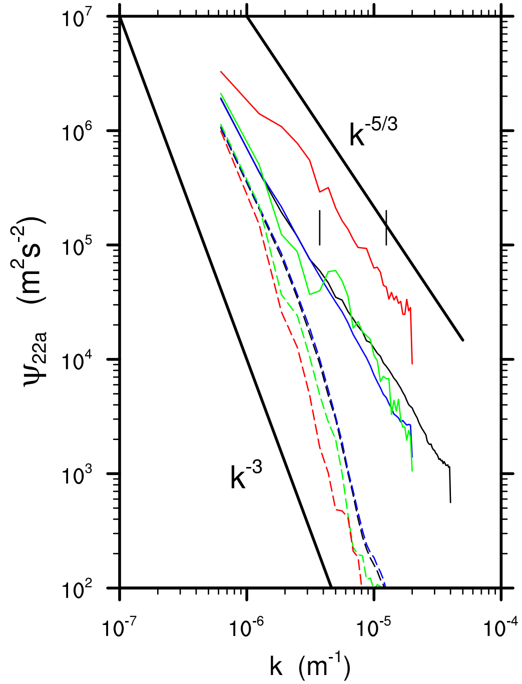
# RAIN

Latitude-time plots
(Averaged over longitude)

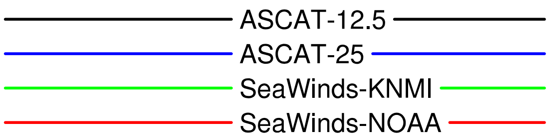


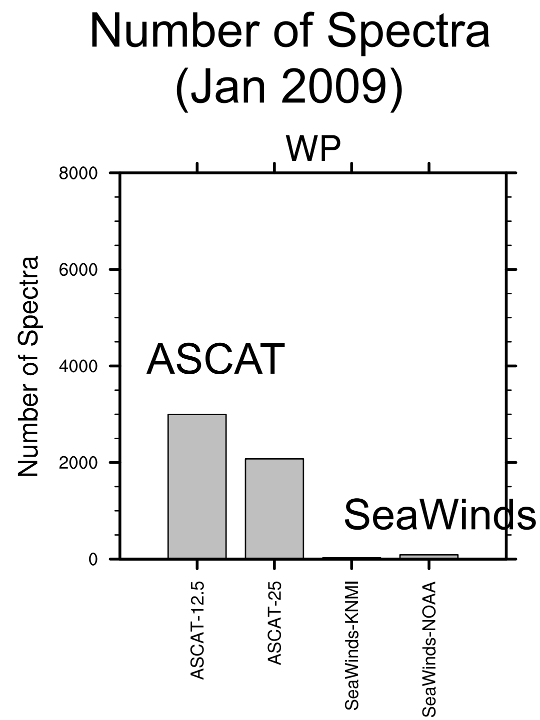

Rain is bad news for SeaWinds.
ASCAT can see through it.

# Spectra




Dashed lines: NWP winds



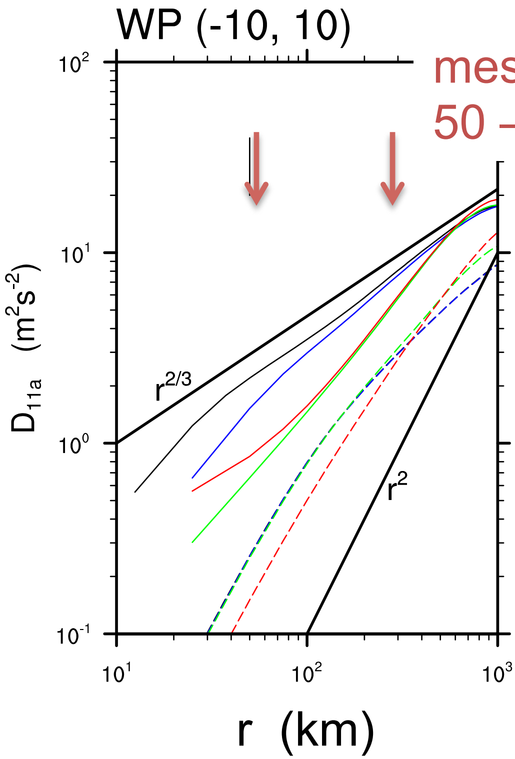



# Structure Functions

$D_{11a}$

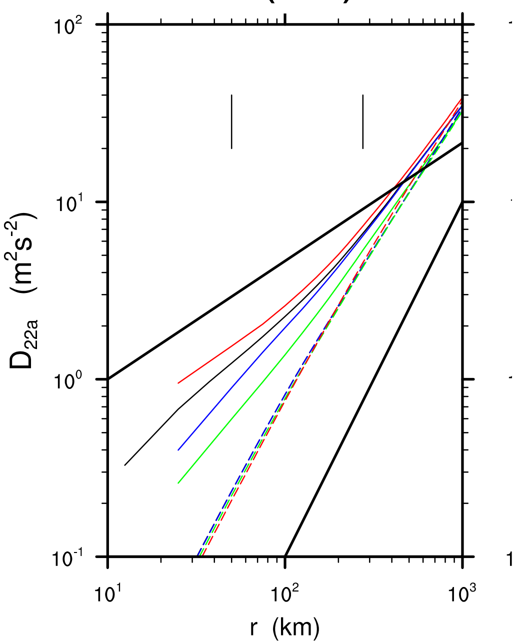
(Merid)

meso-beta:
50 – 250 km

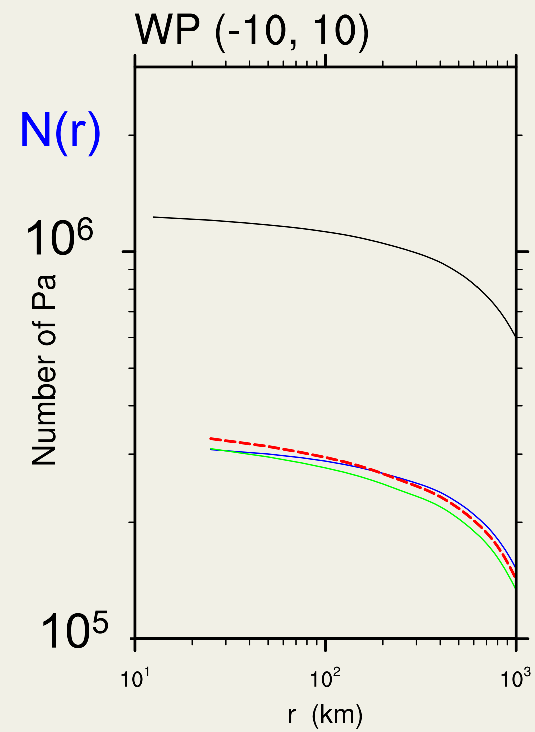



$D_{22a}$

Zonal




Number of velocity differences vs r




Effectively

- ASCAT: 2 or 3 times more
- SeaWinds: > 50 times more

# Tests

- Ratios : $$\frac{D_{22a}}{D_{11a}} \sim \frac{\text{Vorticity}}{\text{Divergence}}$$ Do Vortical or divergent Modes dominate?

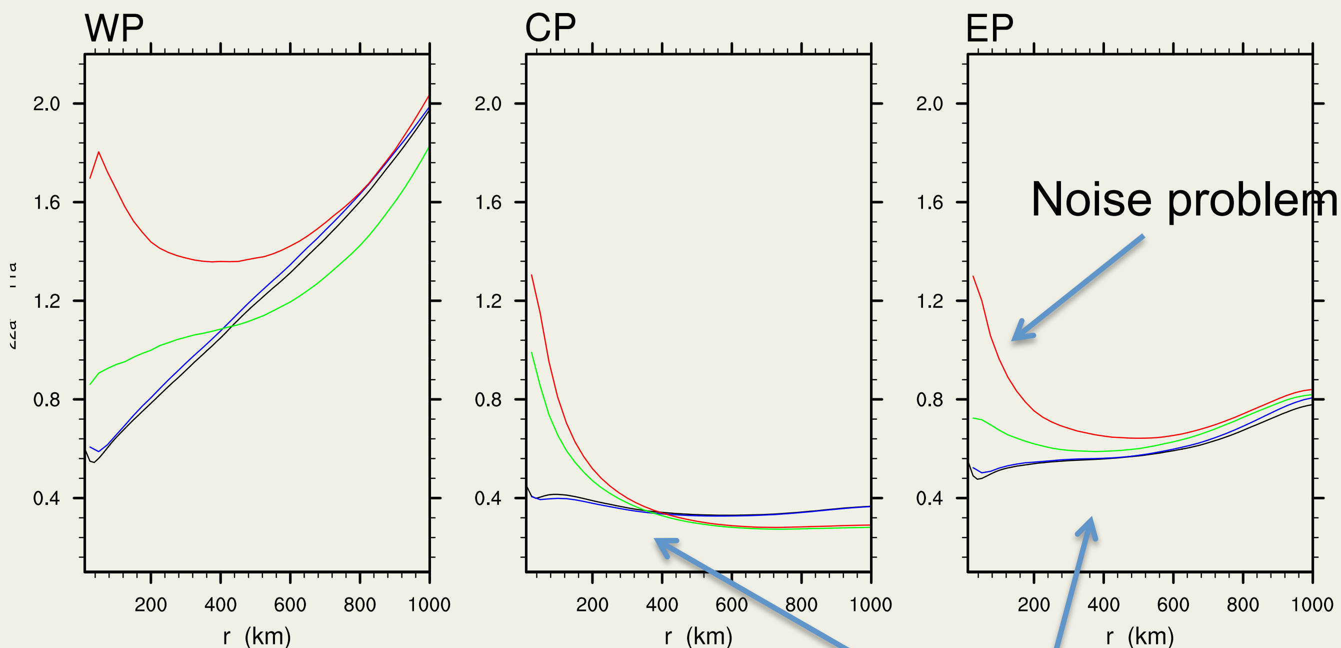
- Power-law exponents (slopes) meso-beta (50 – 250 km)

| | | |
|---|---|---|
| Spectra | $k^{-5/3}$ | $k^{-3}$ |
| SFs | $r^{2/3}$ | $r^{2}$ |

- $D_3 < 0$ (downscale) – good for prediction
  $D_3 > 0$ (upscale) -- bad for prediction

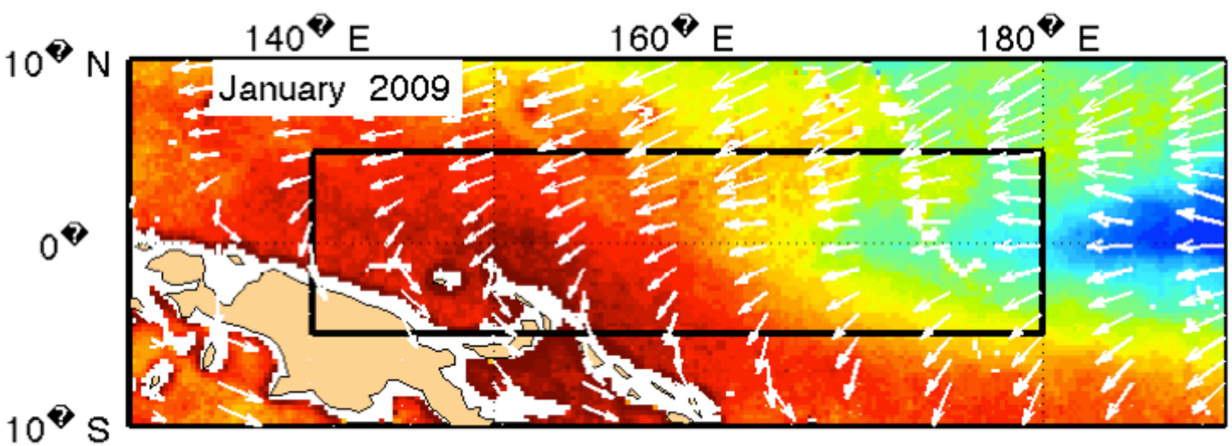
# RATIOS

vorticity
-----------
divergence



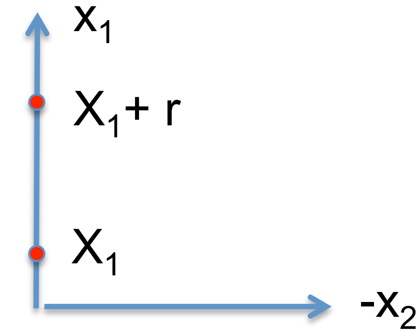

Vorticity < divergence

⇒ Divergent modes
⇒ (gravity waves)
⇒ Downscale ?

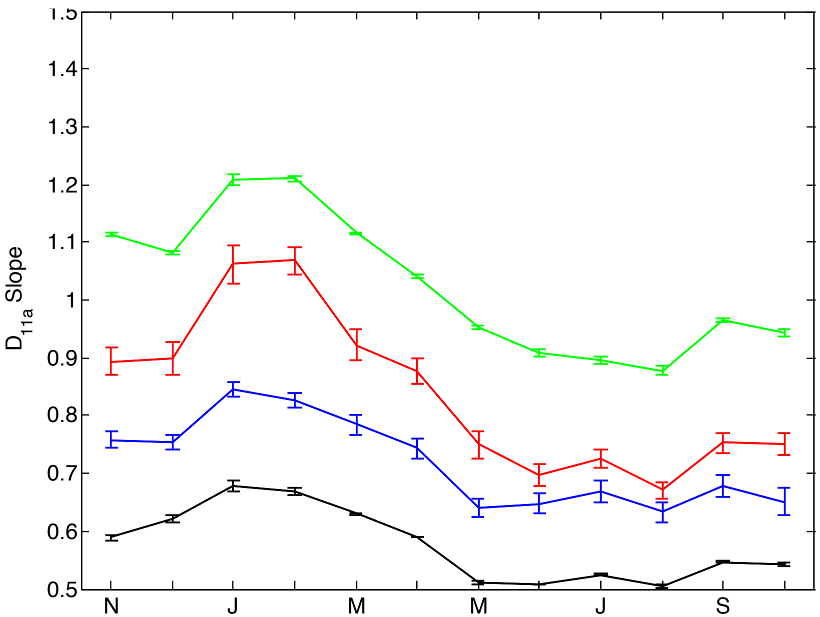


# West Pacific (5S – 5N)

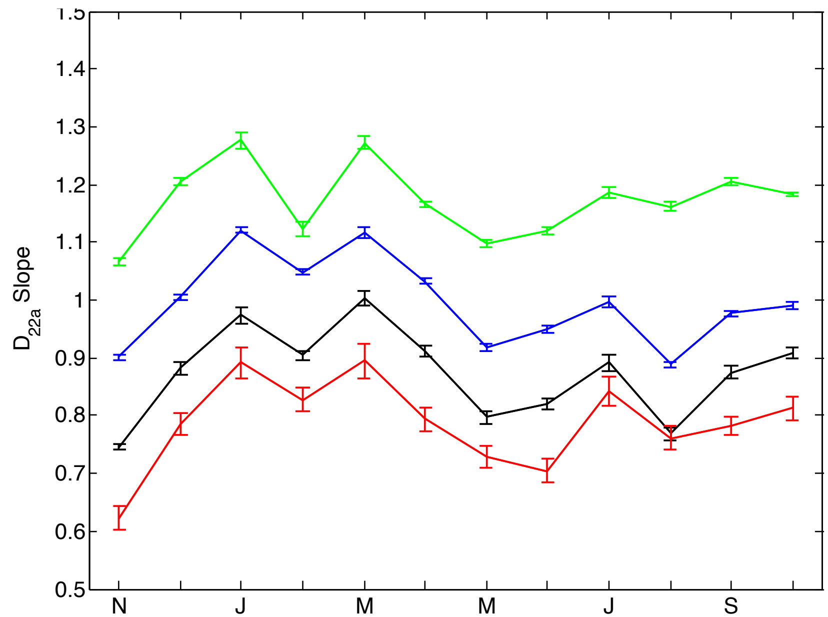
$$D_{11a} = \langle \delta u_1 \delta u_1 \rangle$$
$$D_{22a} = \langle \delta u_2 \delta u_2 \rangle$$




D$_{11a}$ slope




D$_{22a}$ slope

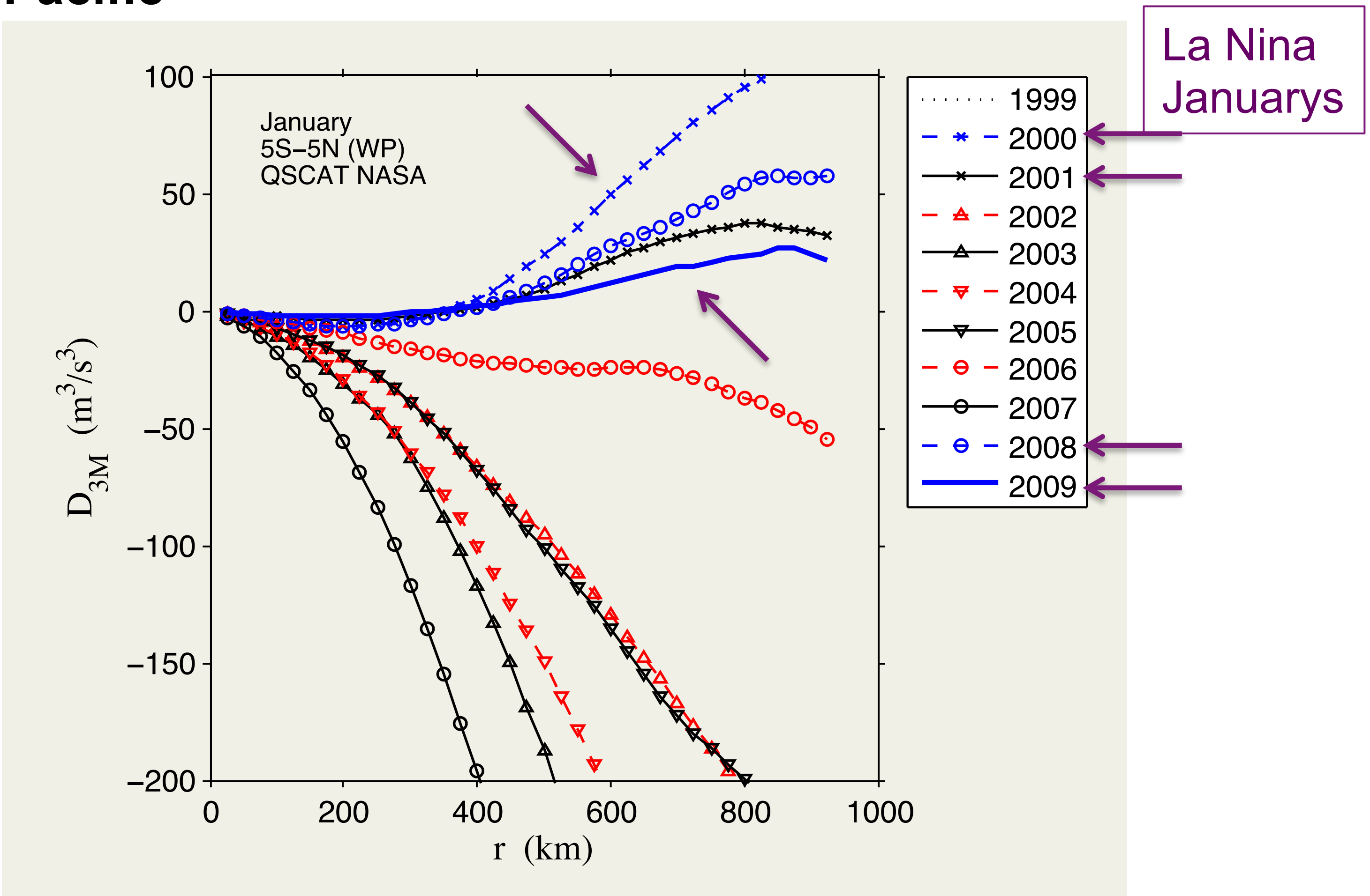



Nov 2008 – Oct 2009

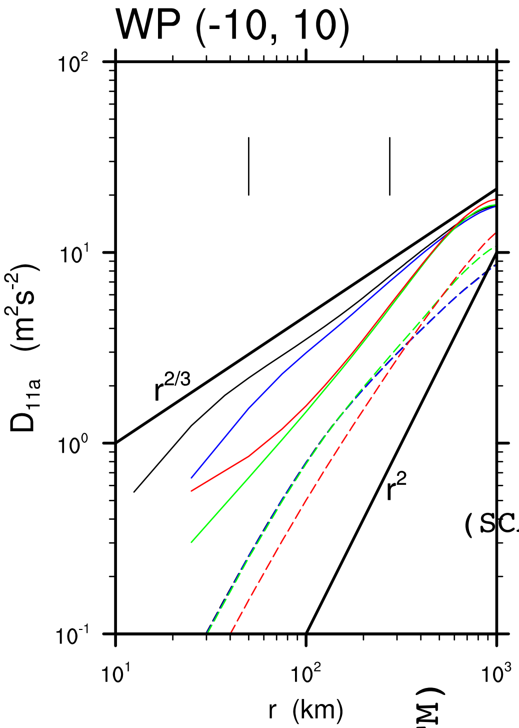
# $D_{3a}(r)$
# All Januaries

$$D_{3a} = \langle \delta u_1 (\delta \vec{u} \cdot \delta \vec{u}) \rangle$$

**West Pacific**

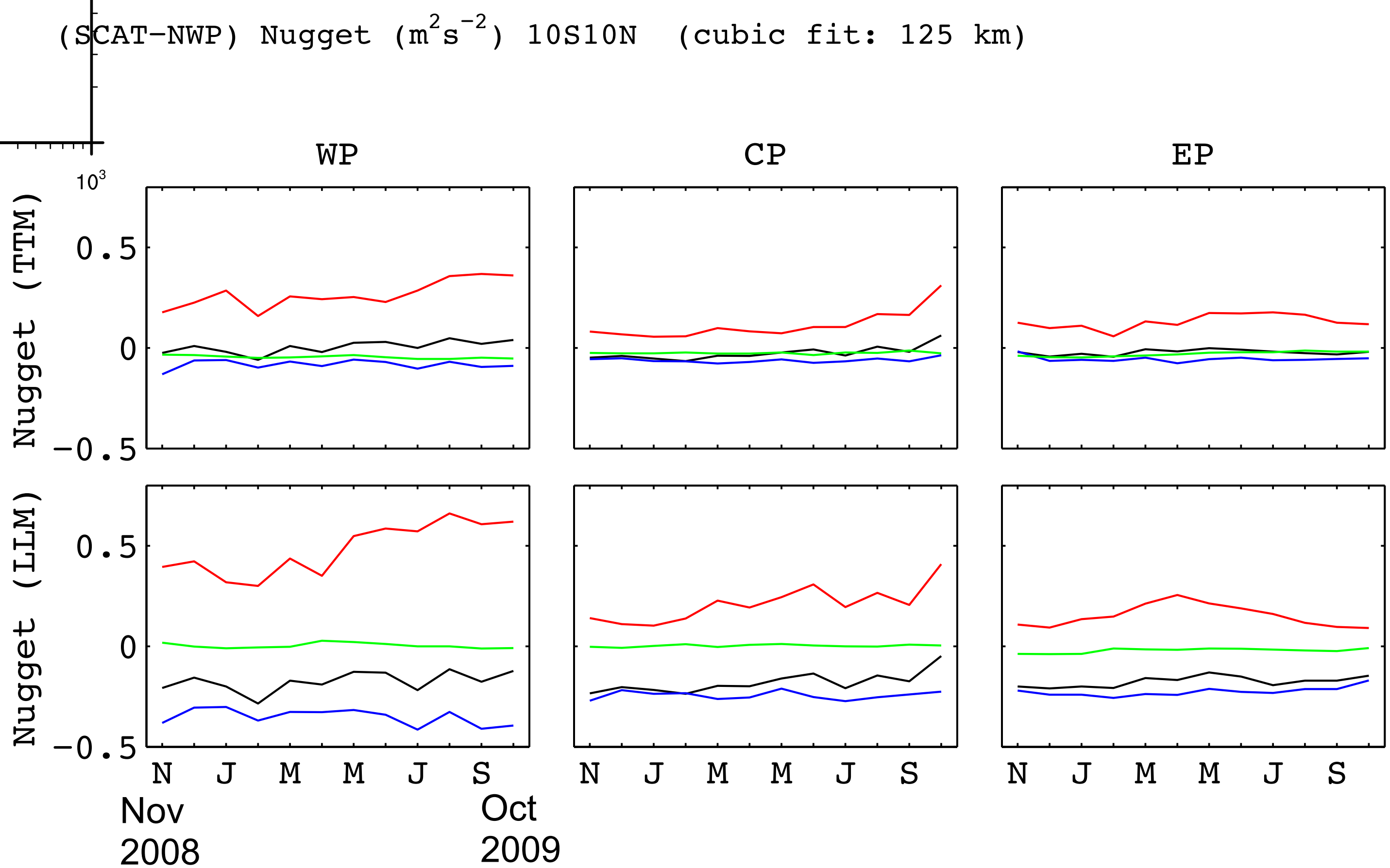


# NOISE
# The r → 0 limit




Noise 22a

Noise 11a



Reports on wind product comparisons will appear on the NWP SAF web site at ...
http://research.metoffice.gov.uk/research/interproj/nwpsaf/vs.html