A hybrid physical-statistical algorithm for SAR wave spectra quality improvement

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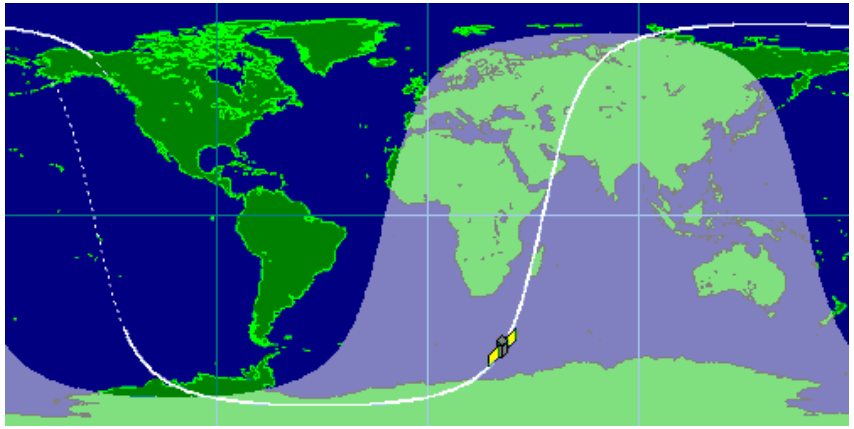
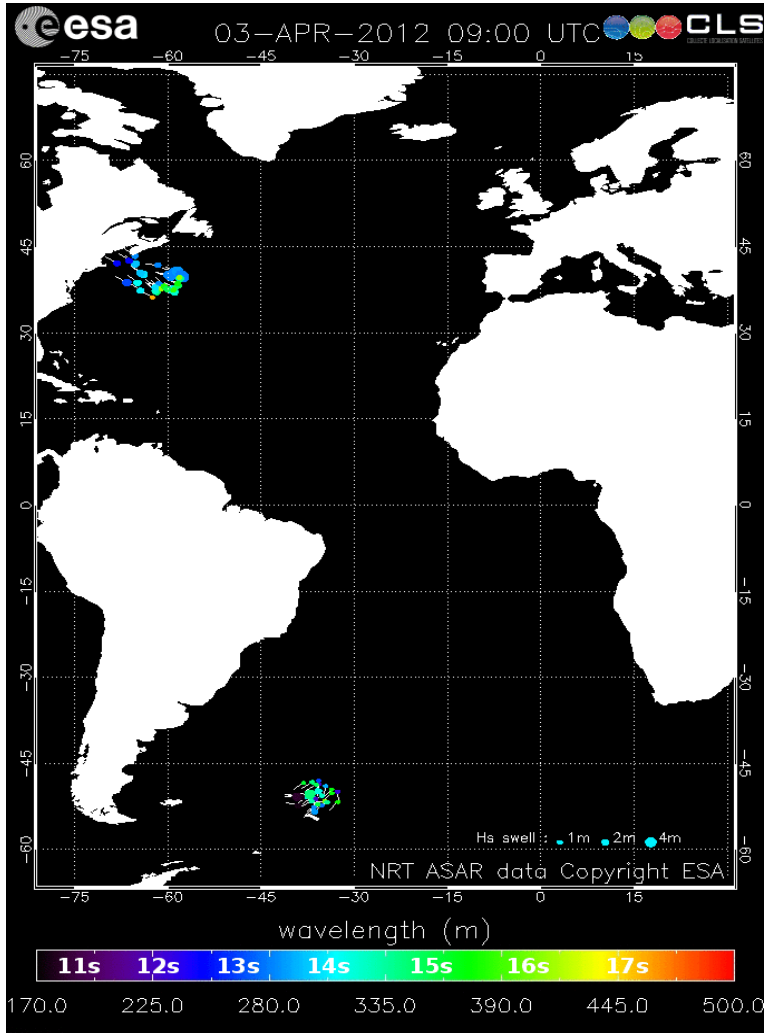
XII SIMPÓSIO SOBRE ONDAS, MARÉS, ENGENHARIA OCEÂNICA E OCEANOGRAFIA POR SATÉLITE .:. 03 a 06 de outubro de 2017, Arraial do Cabo, RJ

introduction

- **ENVISAT**
  - On operation from 1 March 2002 until 9 May 2012
  - Satellite missions equipped with the Synthetic Aperture Radar (SAR) has provided a large amount of important data (spectra) for the ocean wave community
- However, SAR wave spectra have not been used as much as expected
- Known shortcomings in SAR wave spectra.
  - Directional ambiguity
  - Noise (natural variablilty)



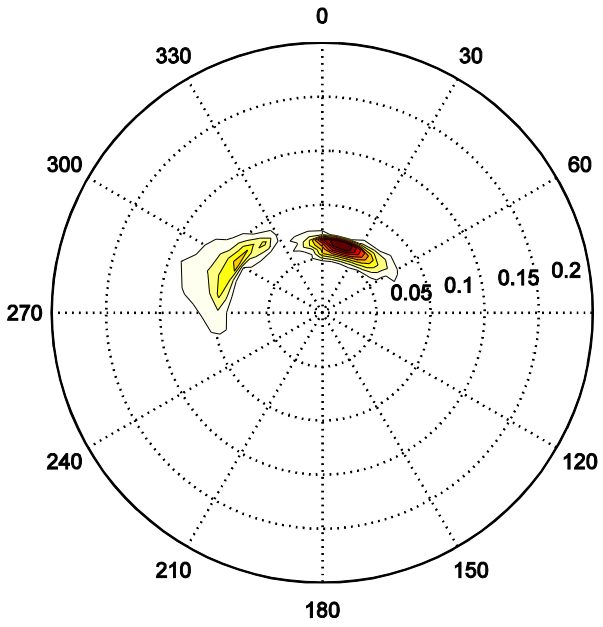
Fireworks product by CLS



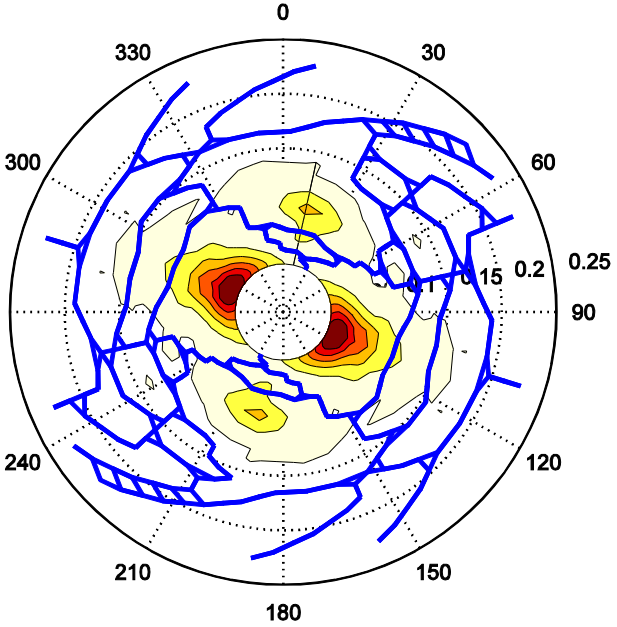
Using GlobWave database

❑ Bad Partitioning

GlobWave spectrum



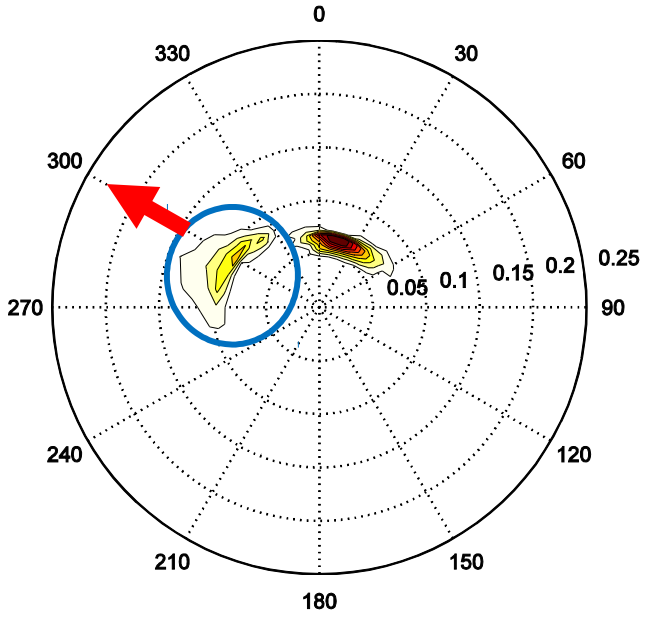
Original spectrum

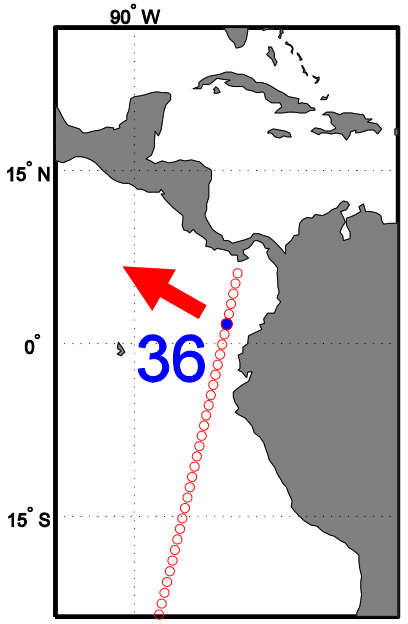


(GlobWave, 2010)

- ❑ GlobWave spectra considers only 2 swell partitions, losing information of other probably important wave systems
- ❑ We found that partitions were not properly determined in the GlobWave data.

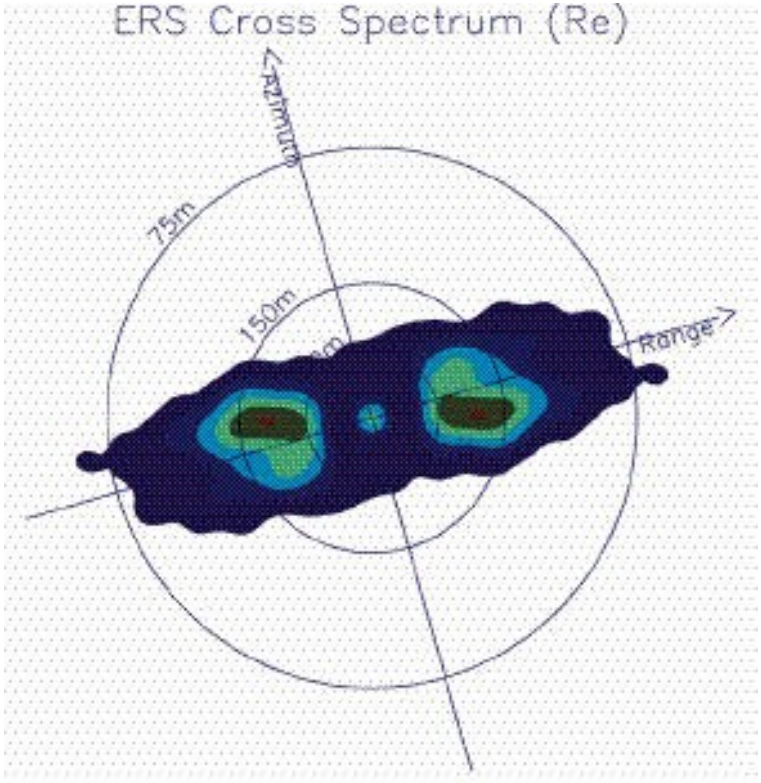
❑ Bad Disambiguation





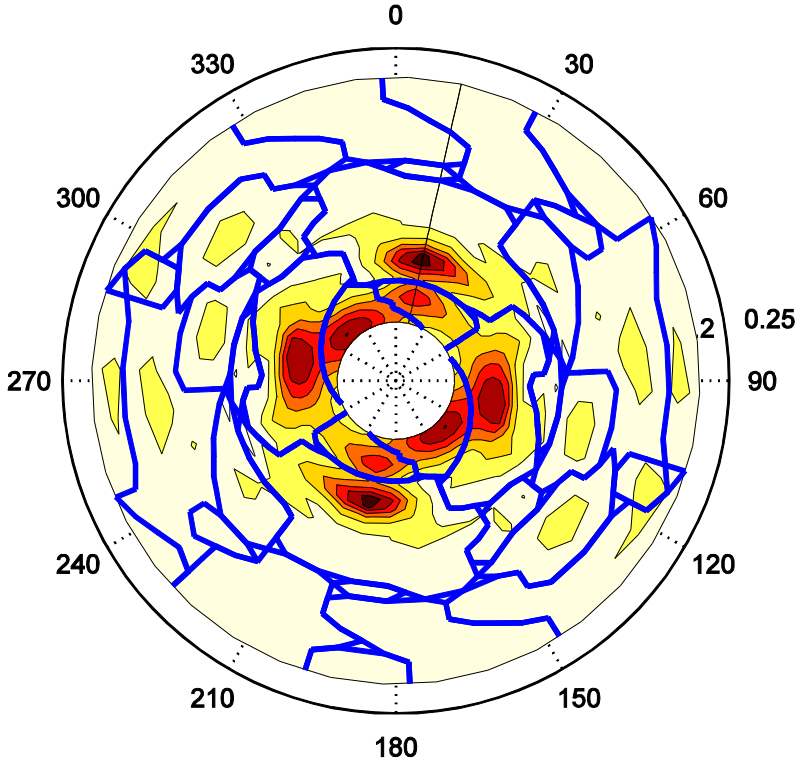
- ❑ Some typical inconsistencies
  - Long waves going offshore (deficient disambiguation)
  - Several ambiguous spectra
  - Deficient partitioning of the 2D spectrum

- In order to carry out a correct disambiguation we take SAR raw wave spectra in N1 format
- Main problems to be tackled:
  - Directional Ambiguity:



(ESA, 2007)

- Noise:



- **Noise Reduction:**
  - Spectra partitioning
  - Identification of noise partitions

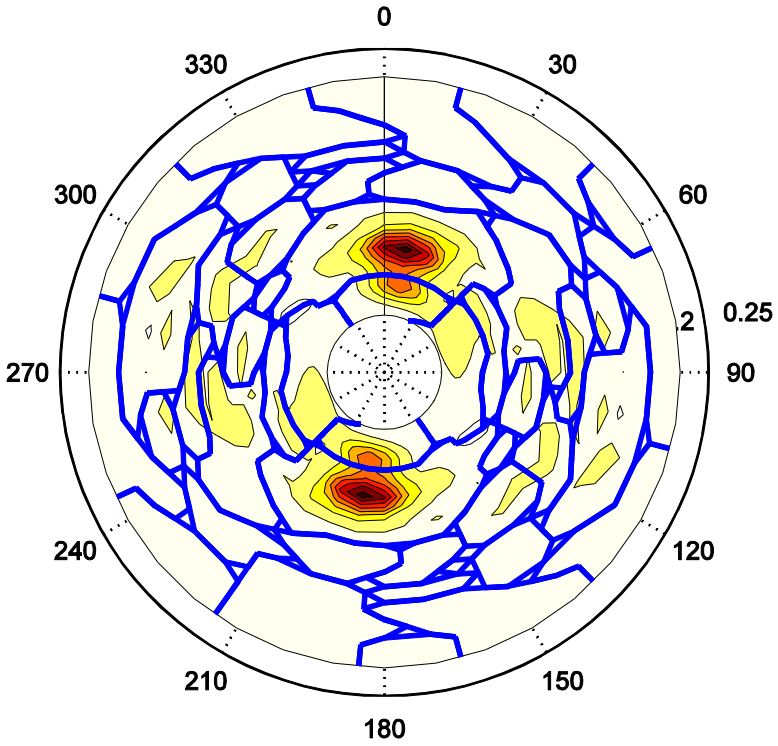
    A large number of low energy partitions.

    Energy decay deviates from exponential to linear.

    More typically found at relatively high frequencies.
    - Noise removal

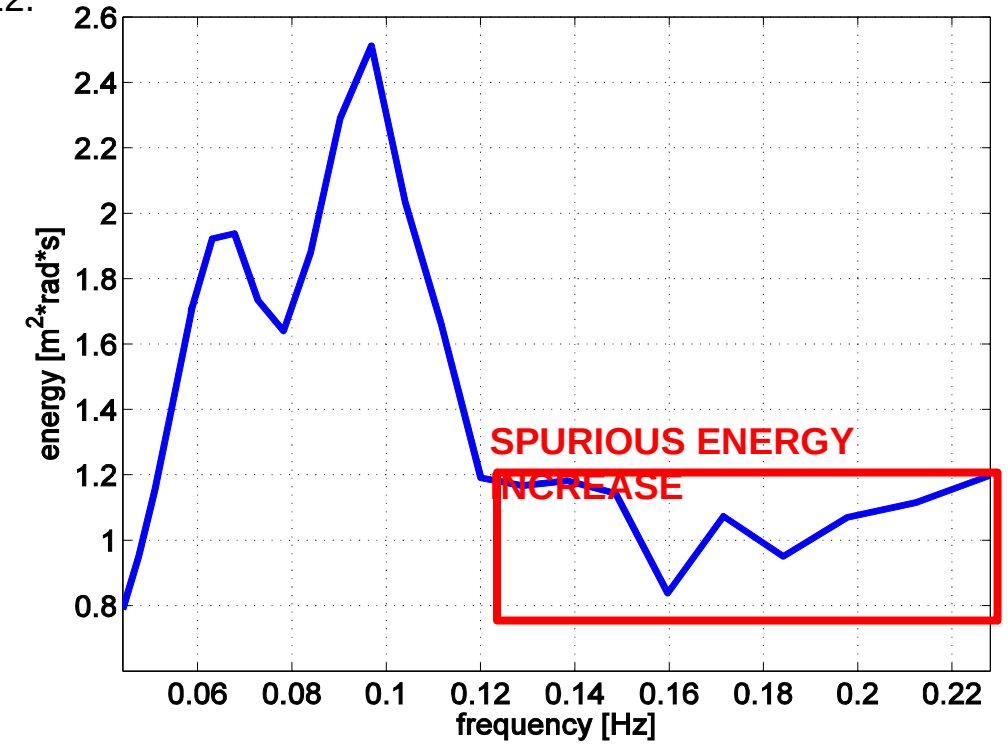
- Disambiguation:

- Spectra Partitioning



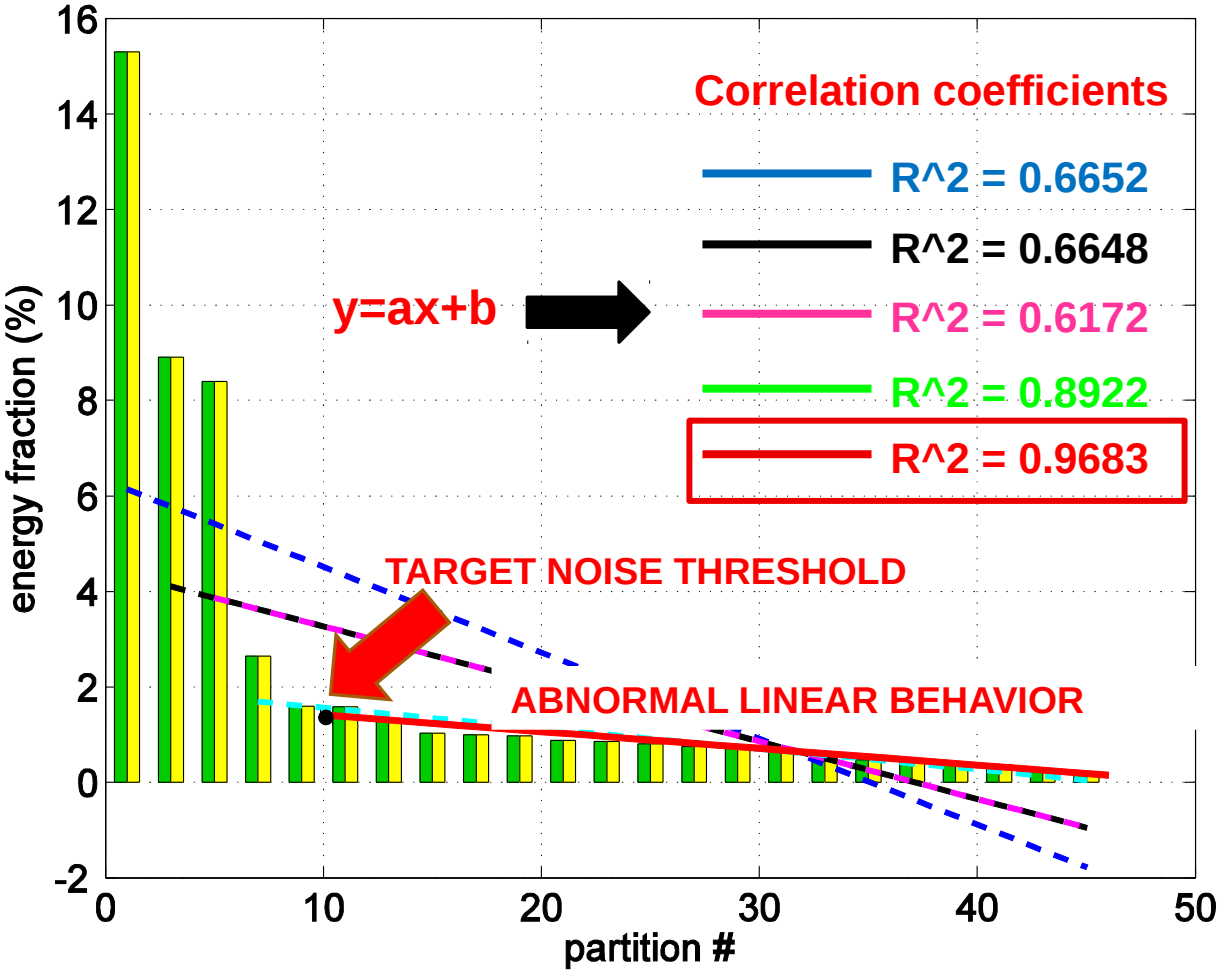
- Partitioning according to (Portilla et al. 2009)
- Consistent partitioning, each partition has a corresponding pair, all pairs are evaluated.
- There is a large number of partitions with low energy, potentially related to noise

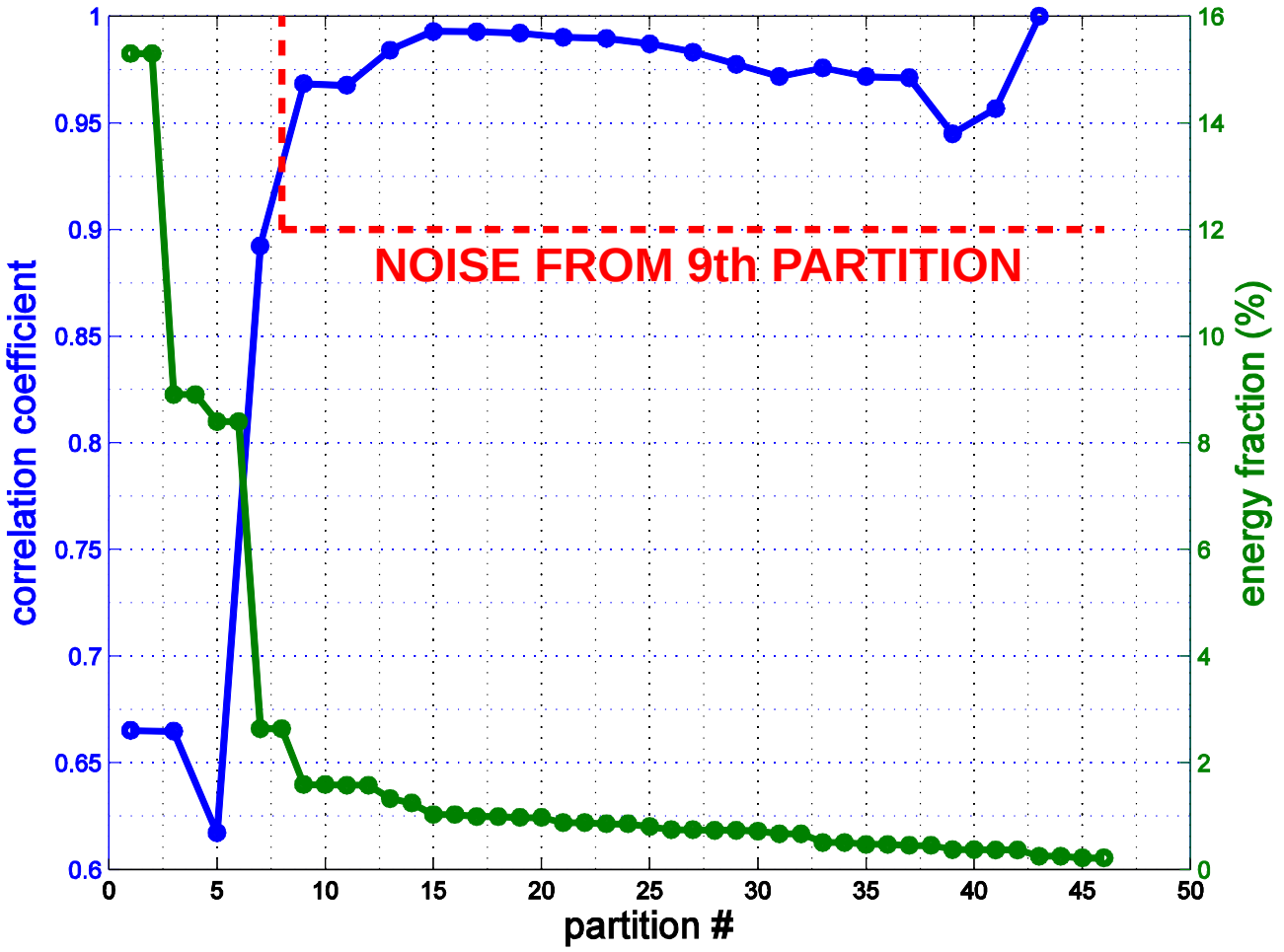
Portilla, J., F.Ocampo, J. Monbaliu, 2009: Spectral partitioning and identification of wind sea and swell. *J. Atmos. Oceanic Technol.*, **26**, 107–122.



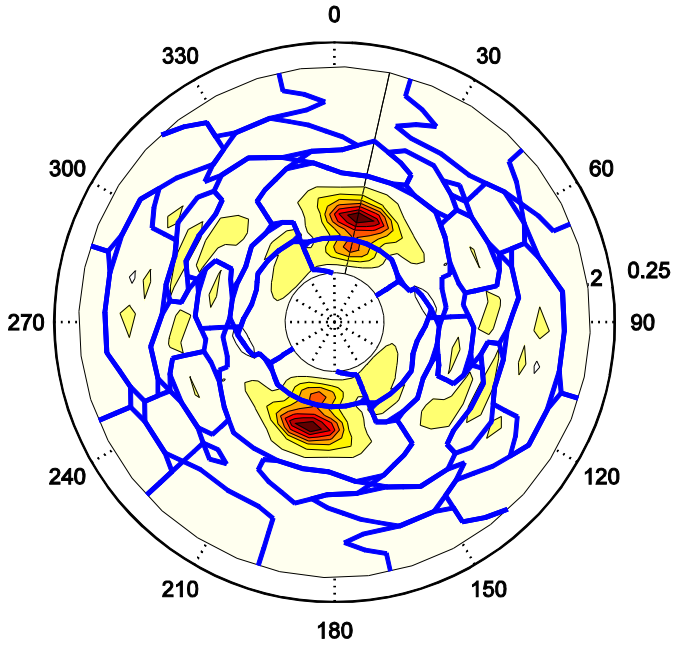
- Small partitions sum up to a spurious large wave system detected generally at high frequencies in the 1D spectrum. This characteristic also hints to the presence of noise.

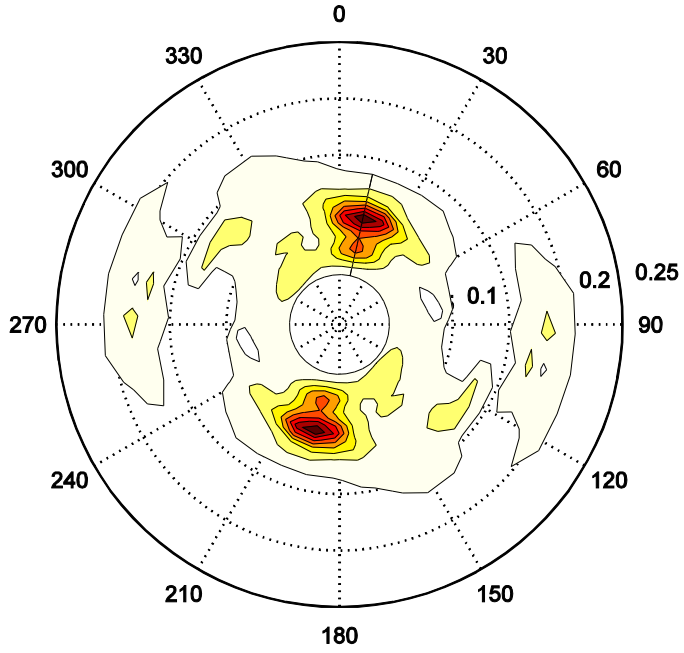
- Criteria for identification of noise partitions: linear energy trend



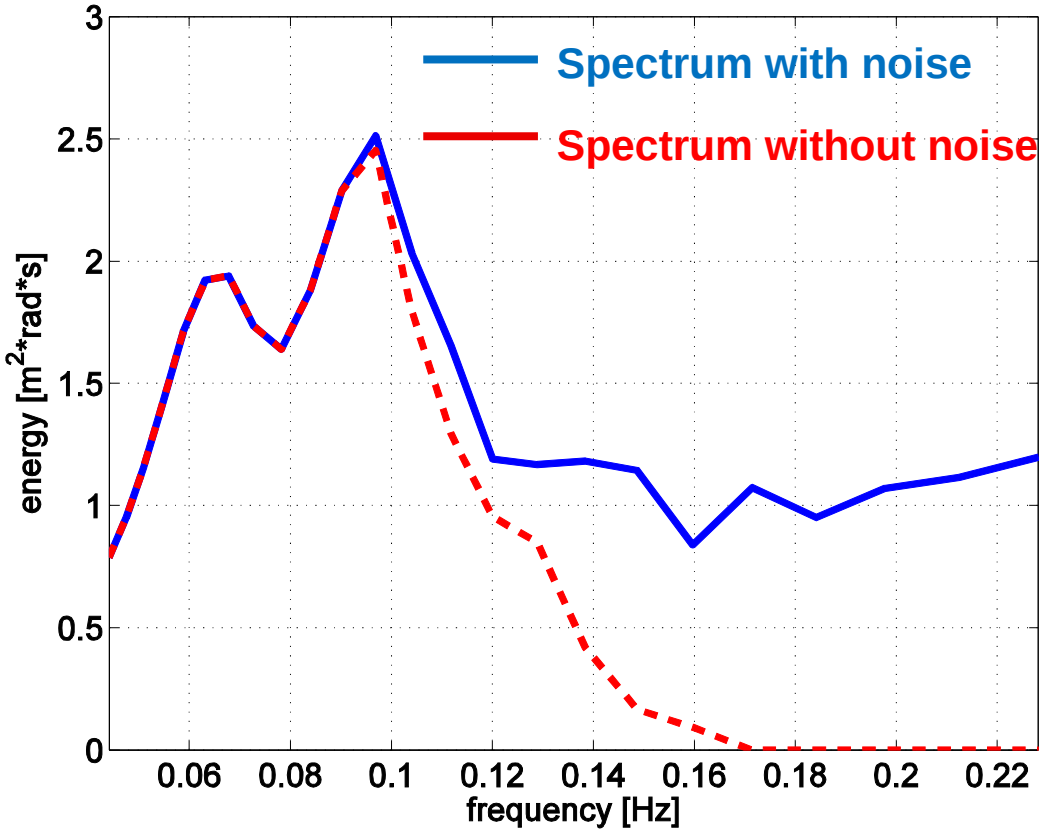


- In the energy rank an abnormal linear decay (expected exponential) hints to the noise threshold limit.
- This threshold is identified by the linear fit (R2) of the partitions energy at low values.



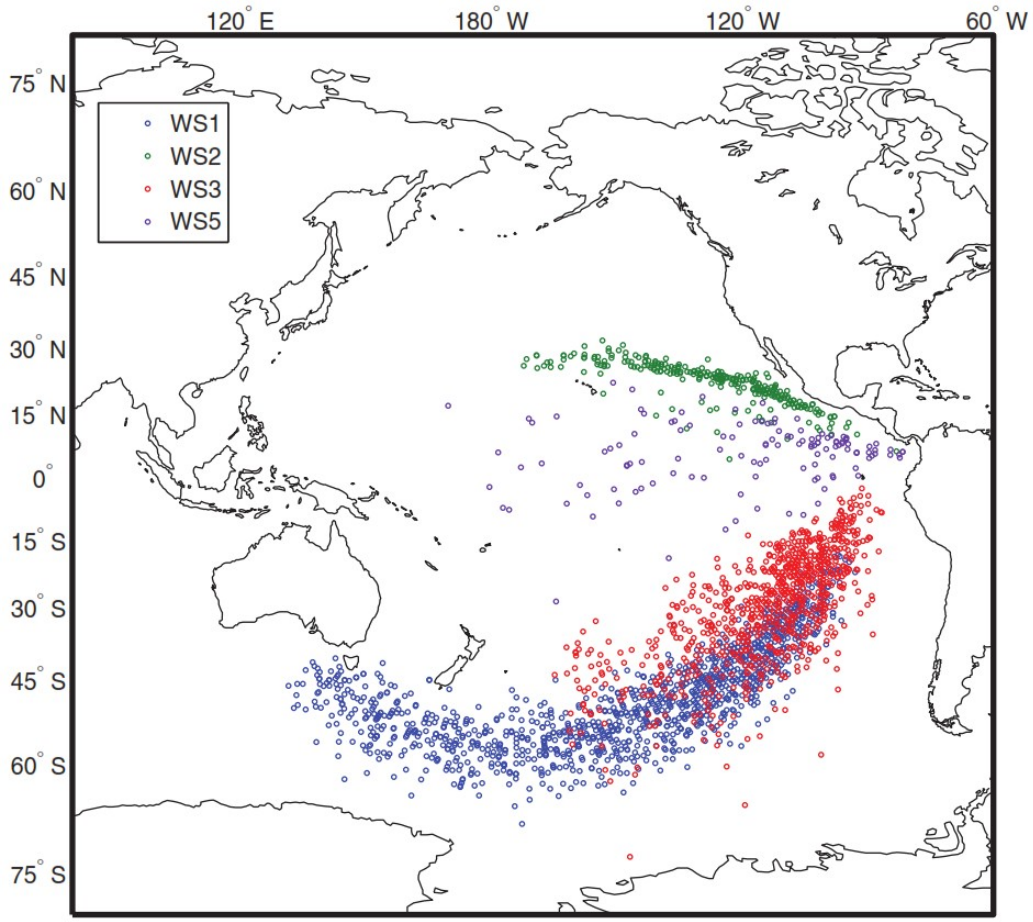


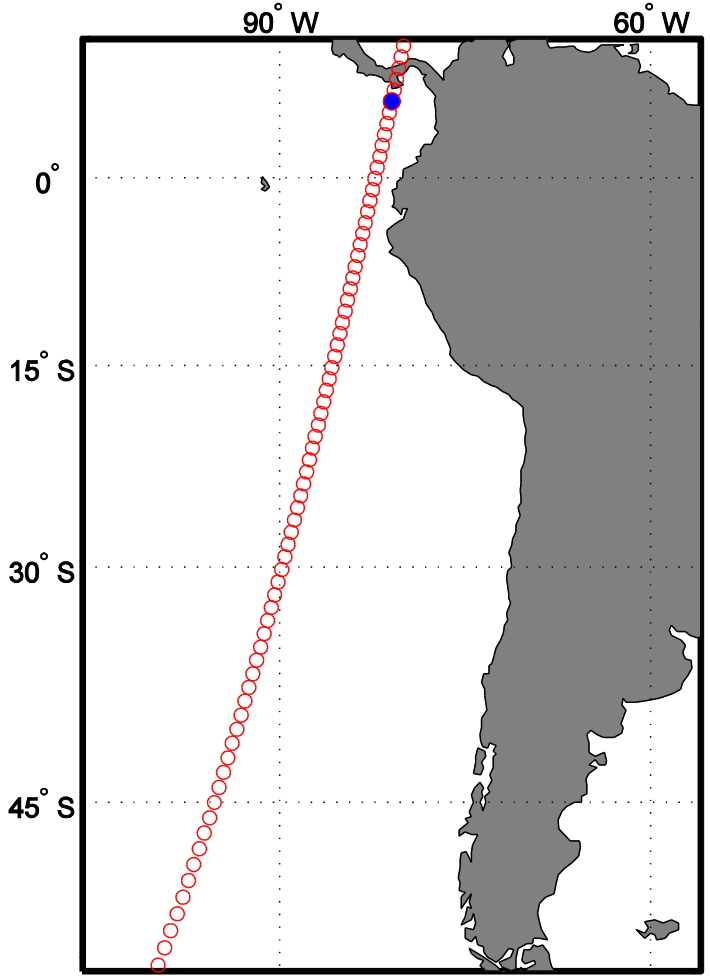
- Noise reduction and assessment of results



- 2D spectra shows the noise partitions removed
- 1D spectra shows a more consistent spectral energy decay

- Noise Reduction:
- **Disambiguation:**
  - Track selection
  - Long term spectral statistics
  - Consistency along the track selected
    - Using previous and next spectrum
    - Using model First Guess
  - Quality flag for disambiguated partitions
  - Assessment of results (comparison with GlobWave spectra)



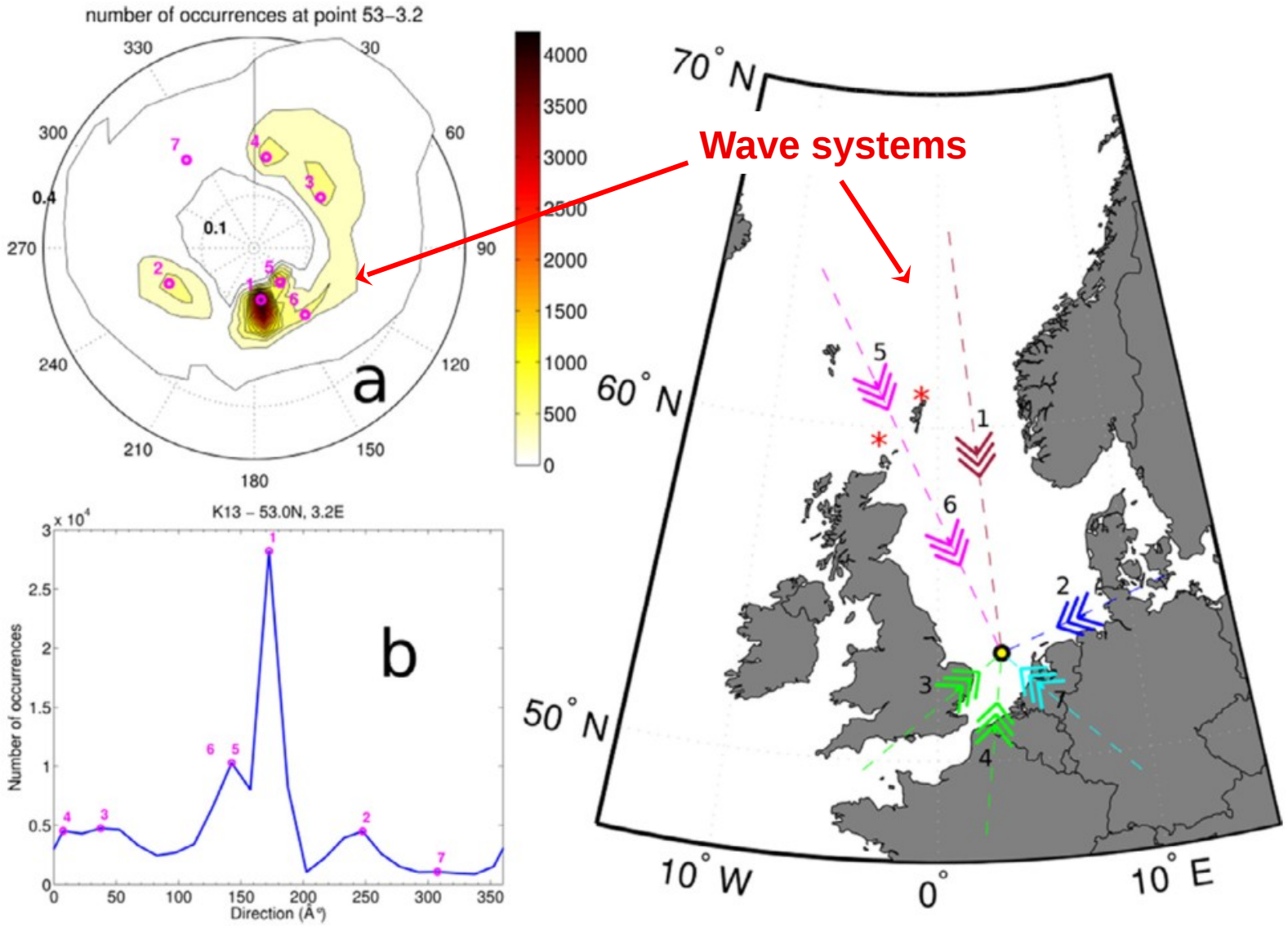


- The Eastern Pacific Ocean is a challenging region
- Presence of swells from northern and southern hemispheres

- A descending track (383) was chosen corresponding to the Boreal winter (18-January-2009)

This in order to satisfy multiple-swell conditions

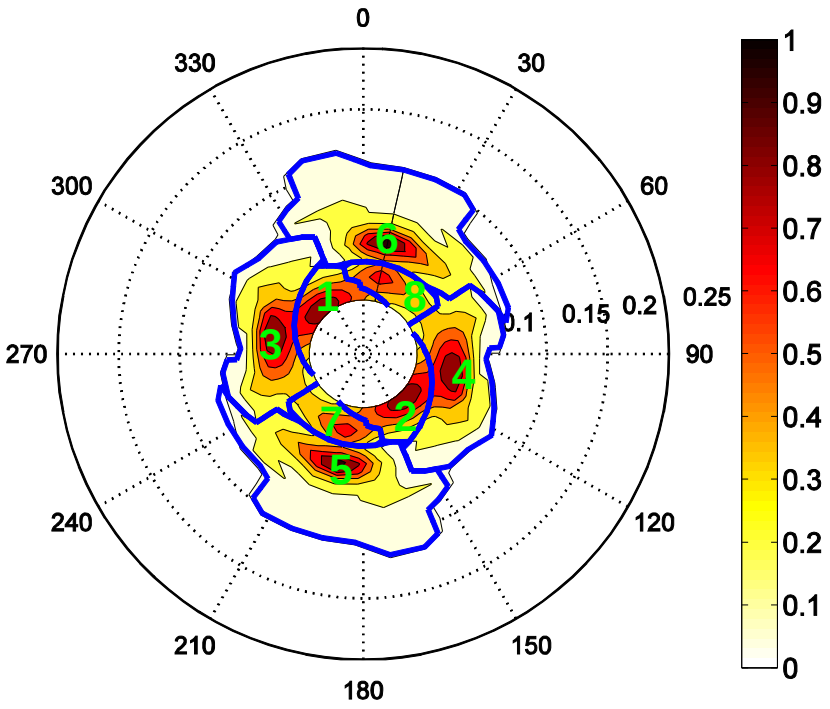
- The main criterion is the use of **long term wave spectral statistics**, from which the occurrence probability of each partition is quantified.
- Spectral statistics are obtained from the ERA-Interim database, encompassing 37 years of spectra at each point.
- Collection of peak frequency-direction positions of all wave systems from a time series of spectral wave data, followed by counting the number of occurrences. (Portilla et al. 2015)



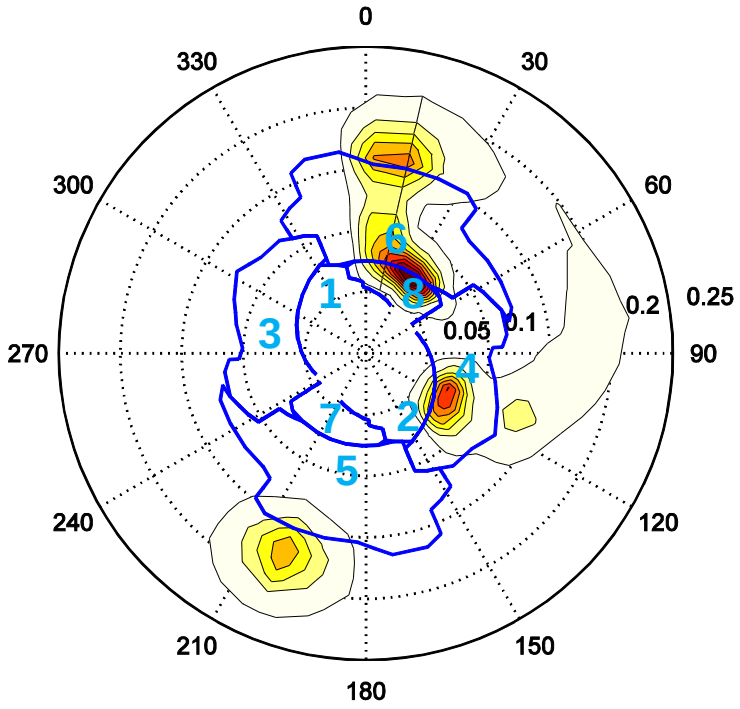
- **Long term spectral statistics** provide more stable and robust results.
- **Four statistical indicators** are analyzed to solve directional ambiguity:
  - **Overall spectral statistics:** Number of occurrences of wave systems along of 37 years of spectra data.
  - **Month spectral statistics:** Number of occurrences of wave systems classified by months providing results for the specific date and month.
  - **Overall weighted spectral statistics:** Gives an estimate of the probability of occurrence of a wave system granted its actual energy.
  - **Month weighted spectral statistics:** Gives an estimate of the probability of occurrence of a wave system granted its actual energy, in the specific month or date.
- The consistency in these four indicators is related to the quality of the disambiguation

EXAMPLE 1

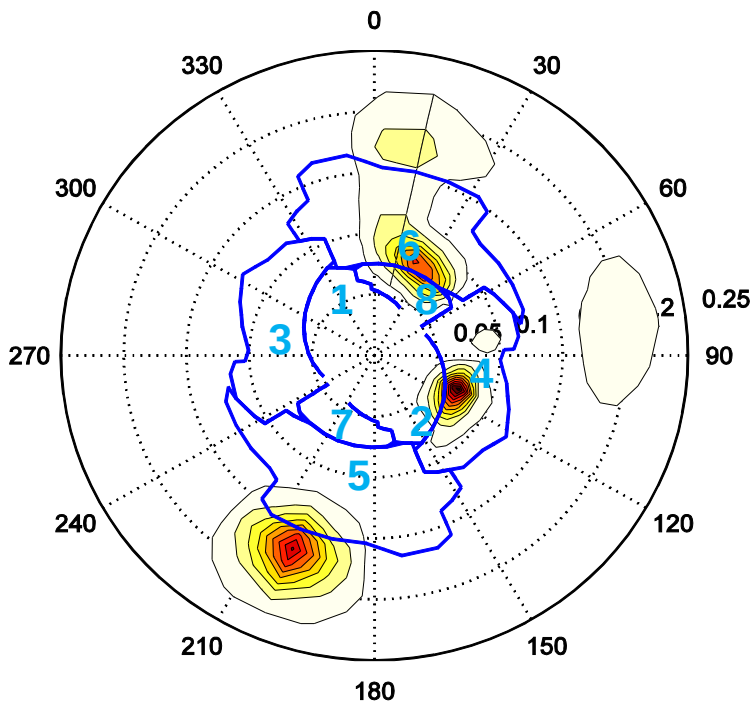
Normalized spectrum



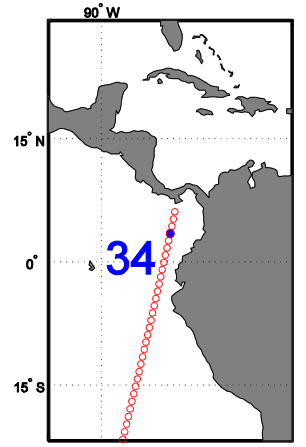
Overall spectral statistics



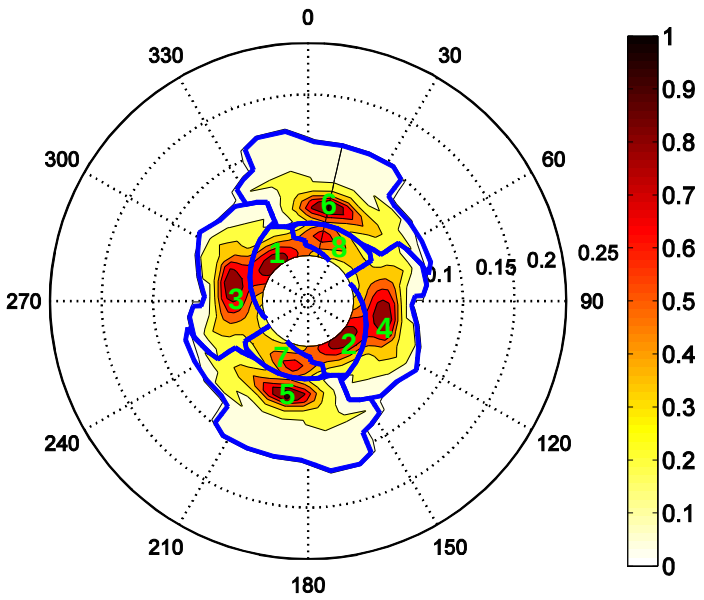
month spectral statistics



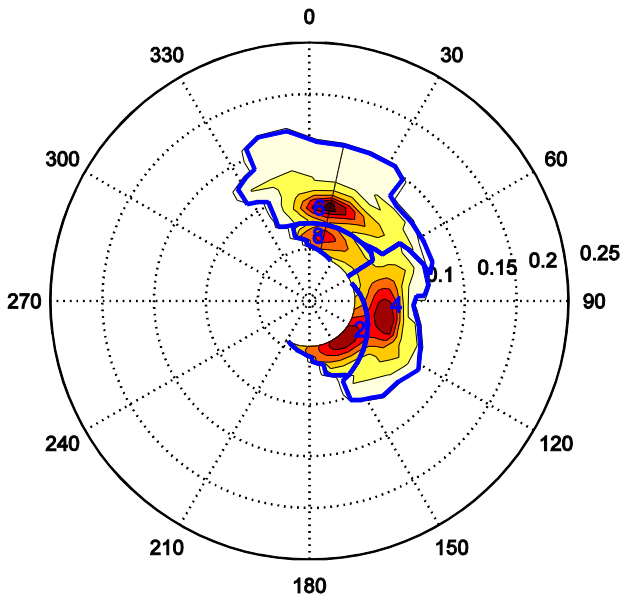
- Probabilities are calculated integrating the number of occurrences (PDF) over the partition domain.



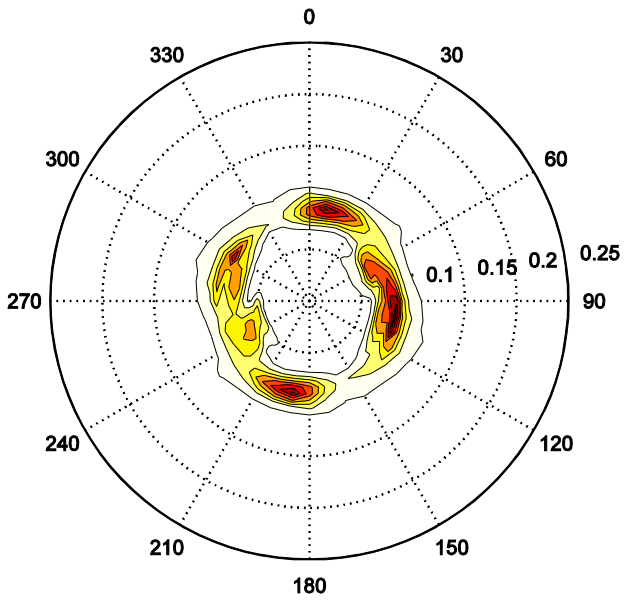
Normalized spectrum



DISAMBIGUOUS SPECTRUM



GLOBWAVE SPECTRUM



OCCURRENCE PROBABILITIES

PARTITION #	OVERALL	MONTH	OVERALL WEIGHTED	MONTH WEIGHTED
1	0 %	0 %	0 %	0 %
2	22.5 %	13.5%	25.2 %	13.7 %
3	0 %	0 %	0 %	0 %
4	32.5 %	43.8 %	35.6 %	54.3 %
5	4.10 %	9.02 %	1.67%	3.4 %
6	31.2 %	28.2 %	26.1 %	23.1 %
7	0.86 %	0.95 %	0.76 %	0.83 %
8	8.98 %	4.26 %	10.4 %	4.51 %

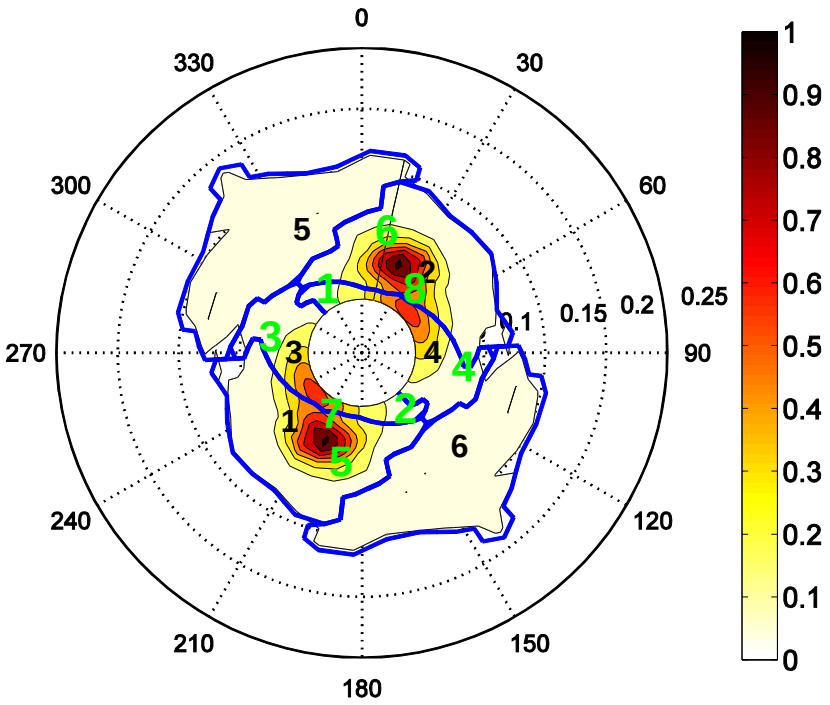
Real Partitions

- Disambiguation with quality flag 1 (**BLUE** in the example shown) is assigned when:
  - All four indicators agree, and
  - The ratio between the probabilities of the real over spurious partition must be at least 10:1.

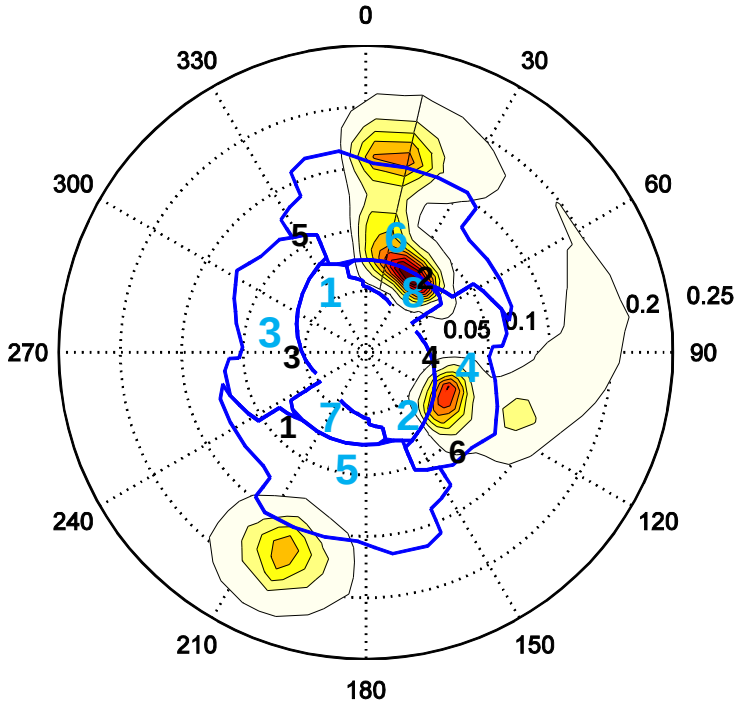
- When not all four statistical indicators agree, or when the ratio of the probabilities between the real over the spurious partition is relatively low, we use other supporting criteria.
- **The main objective of these extra criteria is to keep consistency of partitions along the track**.
  - **Previous and next spectrum:** We reduce the uncertainty comparing the partitions in both the previous or next spectra in the track in the search for disambiguated partitions associated to QF1 (spectral statistics)
  - **Model first guess** provides supporting information when the previous or next spectra are not informative enough.

EXAMPLE 2

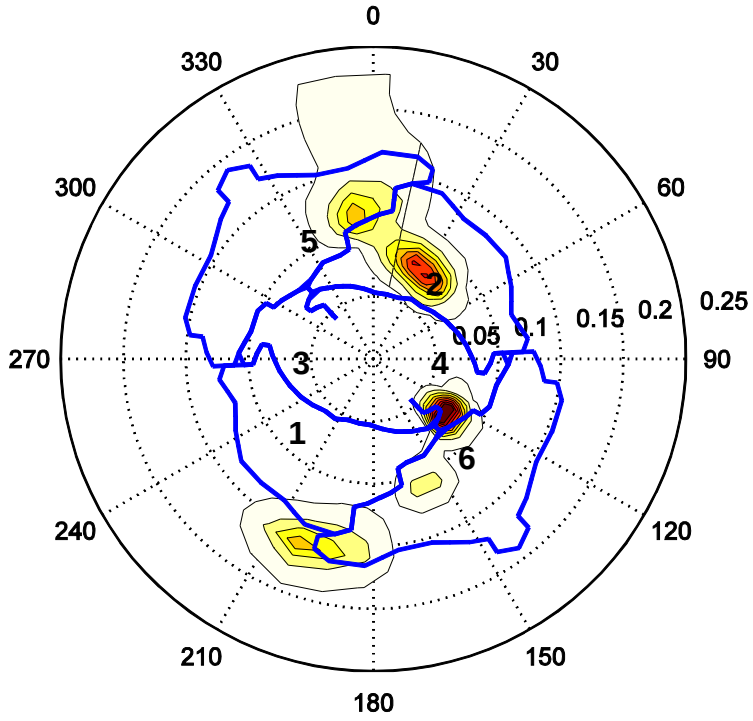
Normalized spectrum



Overall spectral statistics



month spectral statistics

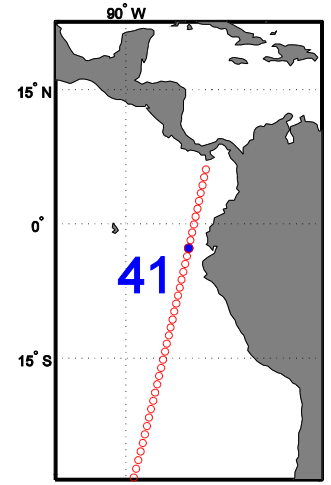


PARTITION #	OVERALL	MONTH	OVERALL WEIGHTED	MONTH WEIGHTED
1	5.71 %	9.59 %	1.29 %	2.67 %
2	57.6 %	48.8 %	83.6 %	80.6 %
3	7.43 %	13.5 %	2.15 %	4.74 %
4	10.7 %	12.8 %	8.48 %	7.22 %
5	7.2 %	5.73 %	1.67%	1.65 %
6	11.1 %	9.45 %	2.78 %	3.07 %

QF1 partitions: All parameters agree

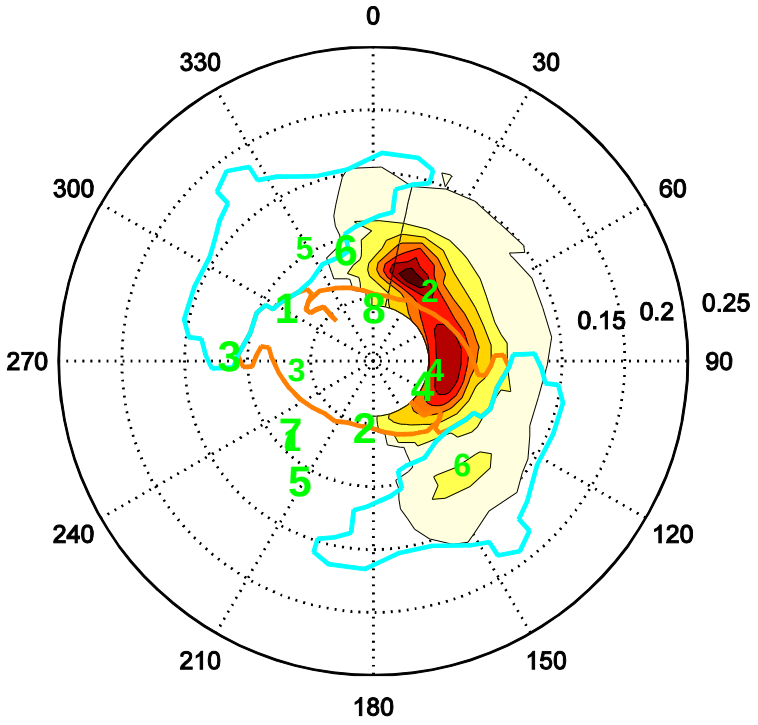
QF6 partitions: 3 parameters agree

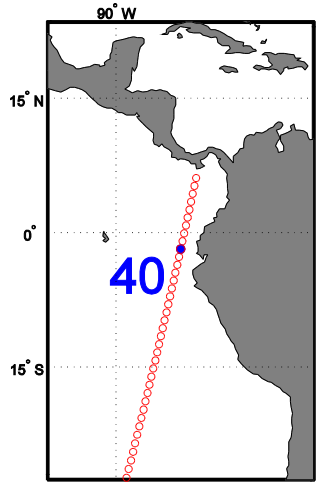
QF4 partitions: All parameters agree, ratio<10:1



previous and next spectrum

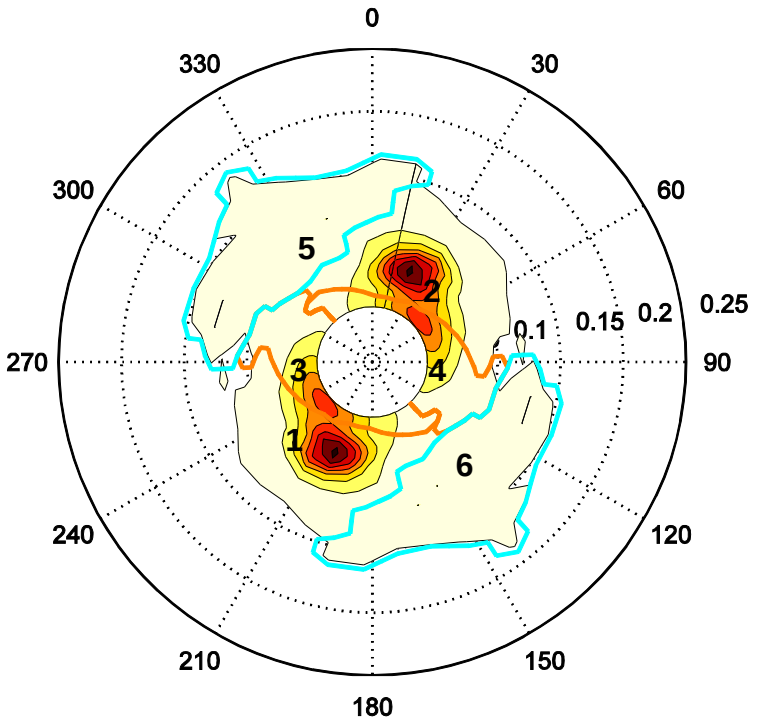
Previous spectrum

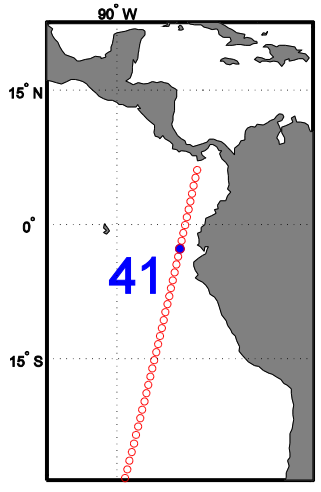




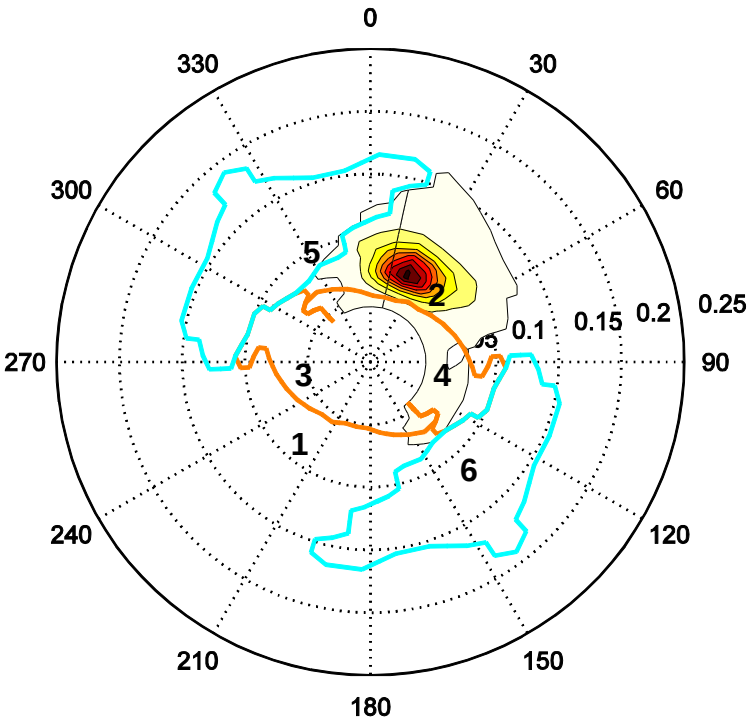
QF1 spectrum

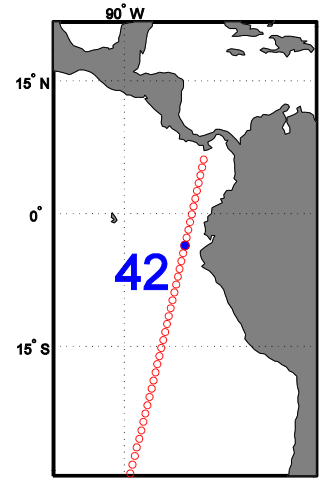
TARGET spectrum





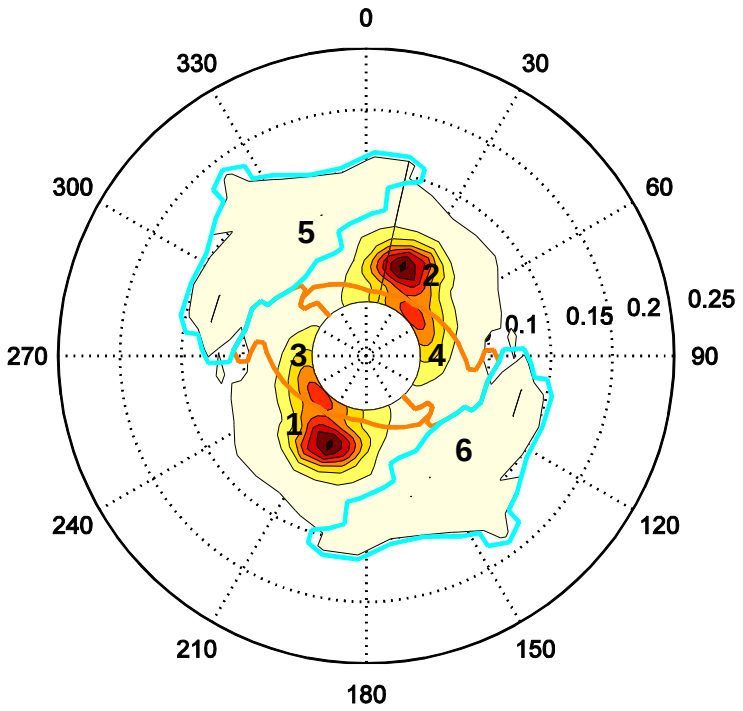
Next spectrum



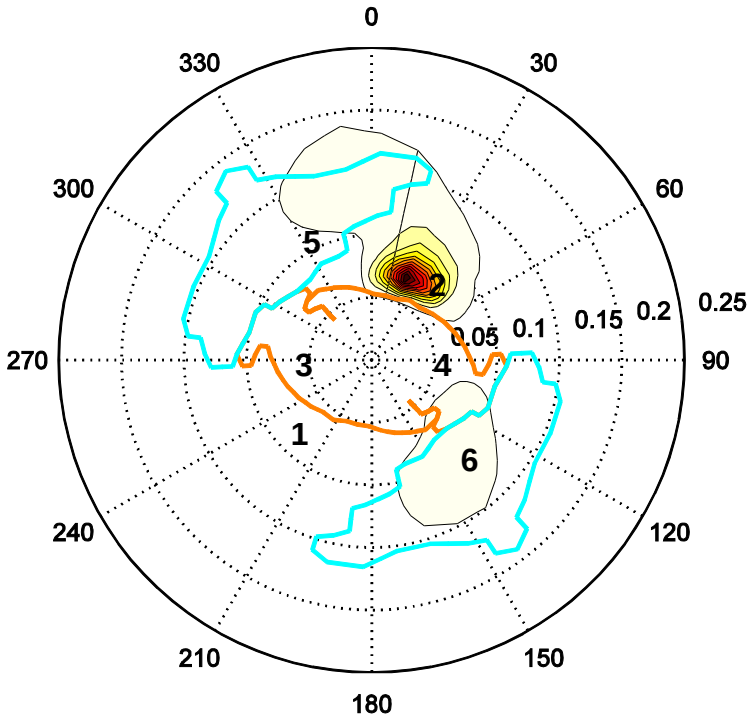


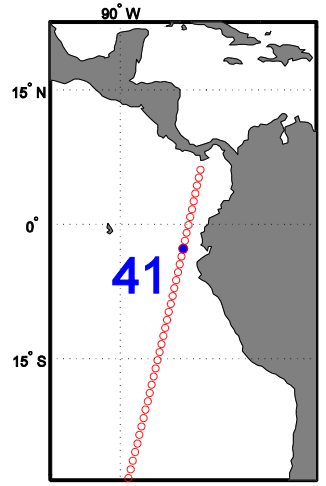
QF1 spectrum

TARGET SPECTRUM



Model first guess





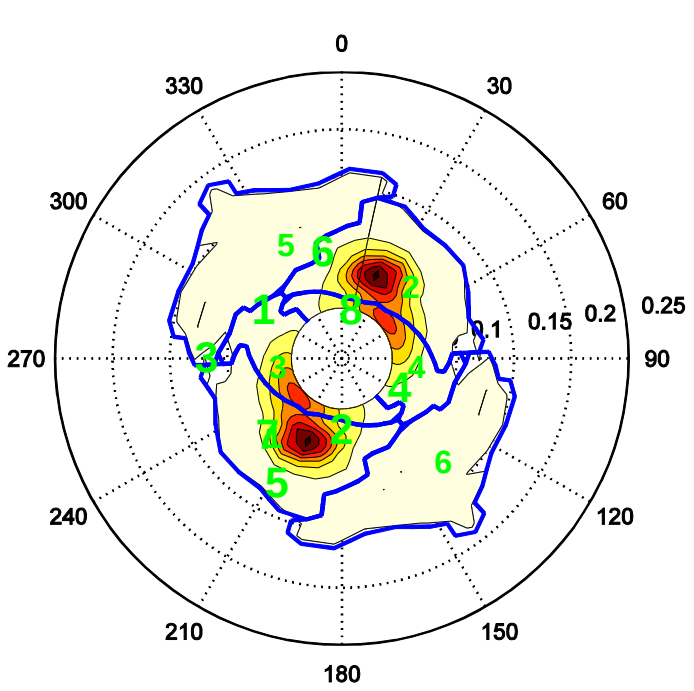
PARTITION #	PREVIOUS	NEXT	MODEL
3	7.15 %	1.48 %	1 %
4	47.4 %	17.5 %	8.48 %
5	0.92 %	0.52 %	3.94%
6	5.94 %	0 %	8.8 %

Real Partitions

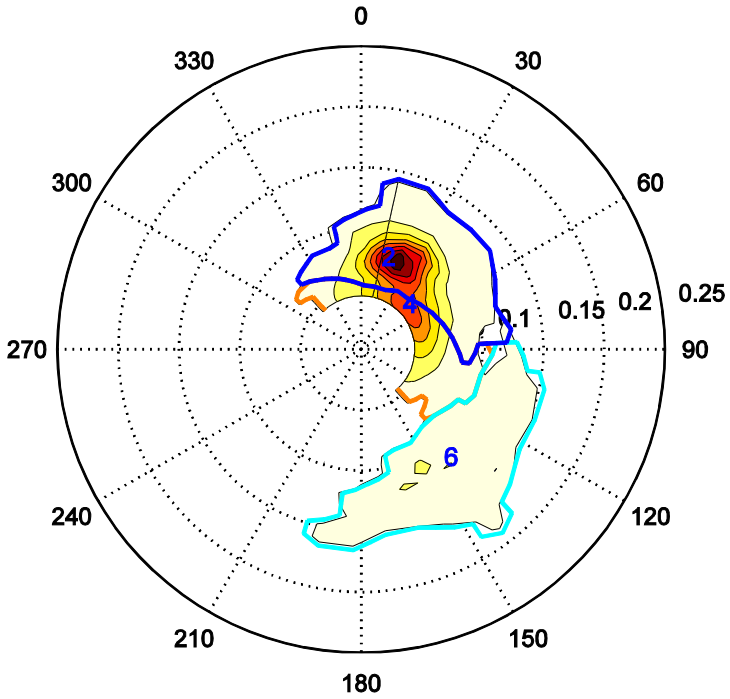
- Supporting criteria: previous, next spectrum or model first guess are used for complicated partitions in order to support the assessment

CONSISTENCY ALONG THE TRACK

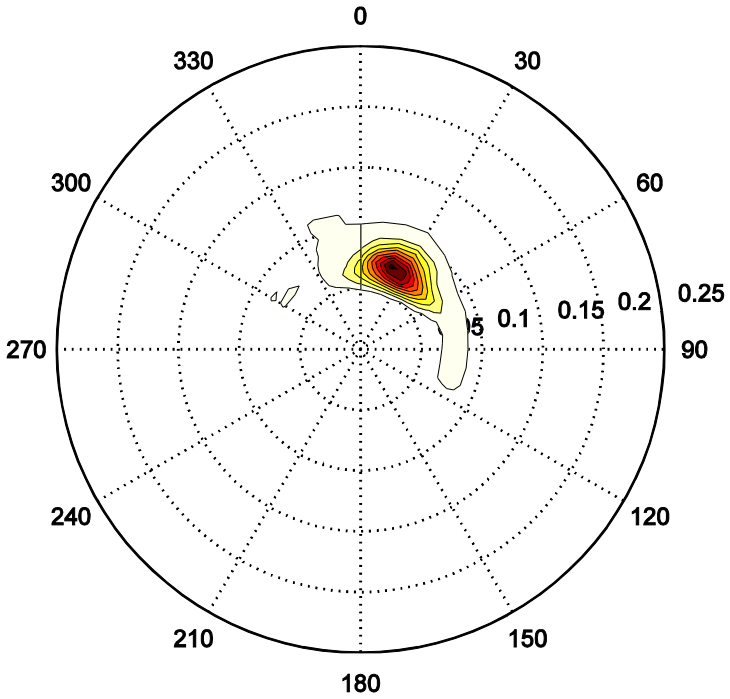
TARGET SPECTRUM



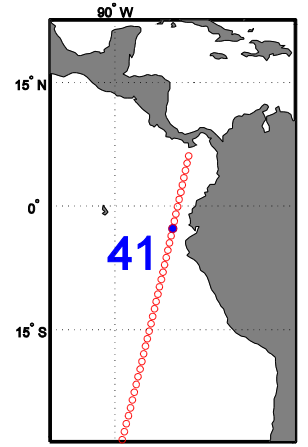
Disambiguous spectrum



Globwave spectrum



- The comparison with the previous and next spectra helps to keep directional consistency along the track.
- GlobWave spectrum misses 2 partitions (swell in gray color)

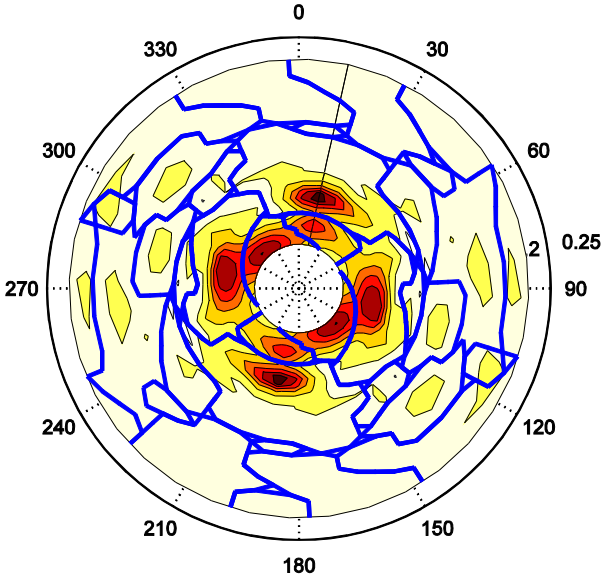


quality flag for disambiguated partitions

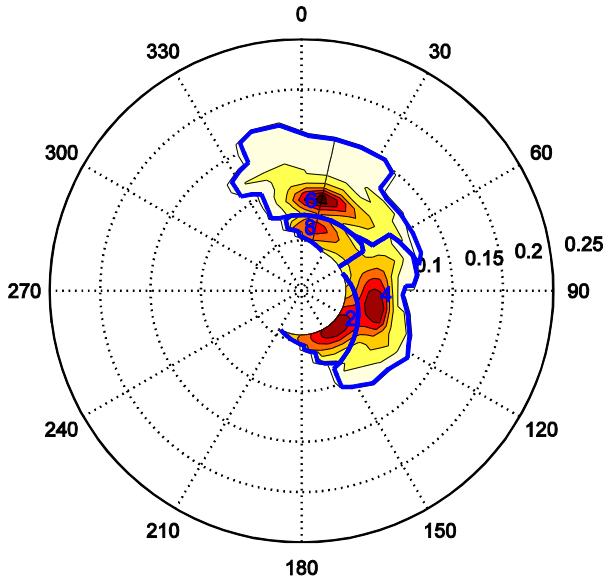
2

Quality Flag	Criteria			Partitions #	Partitions %	Energy %
	Probability parameters agree	Ratio between real probability over spurious	Support Criteria			
QF1	All four	>10 :1		**380**	**54.59 %**	**73.43 %**
QF2		>3:1	previous and next QF1 partitions	**12**	**1.72 %**	**3.09 %**
QF3			model first guess.	**4**	**0.57 %**	**0.95 %**
QF4		>1:1	previous or next QF1 partitions, or model first guess.	**136**	**19.54 %**	**16.04 %**
QF5		Sum of probabilities and energy of partitions are too low (< 2%)	(Consistent noise)	**114**	**16.38%**	**2.96 %**
QF6	3 of 4		previous or next QF1 partitions, or model first guess	**12**	**1.72 %**	**1.53 %**
QF7	2 of 4		previous or next disambiguated partitions of any type from QF1 to QF6, or model first guess.	**16**	**2.30 %**	**1.03 %**
QF8			previous or next disambiguated partitions of any type from QF1 to QF7, or model first guess.	**6**	**0.86 %**	**0.52 %**
noise	2 of 4	Sum of probabilities (<2%)		**16**	**2.30 %**	**0.44 %**

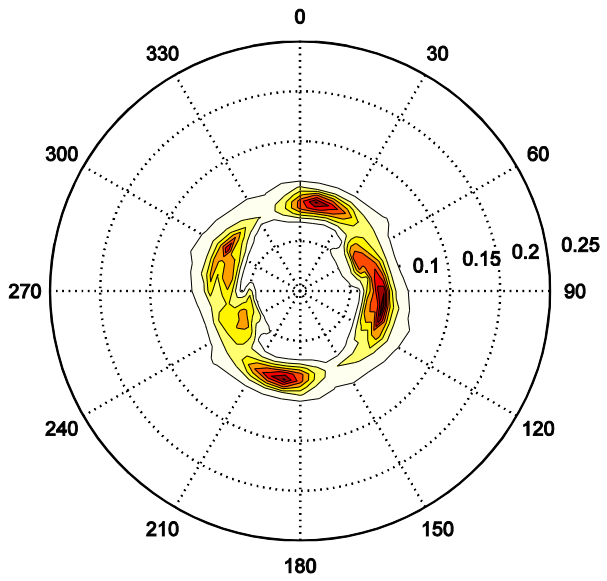
Ambiguous Spectrum



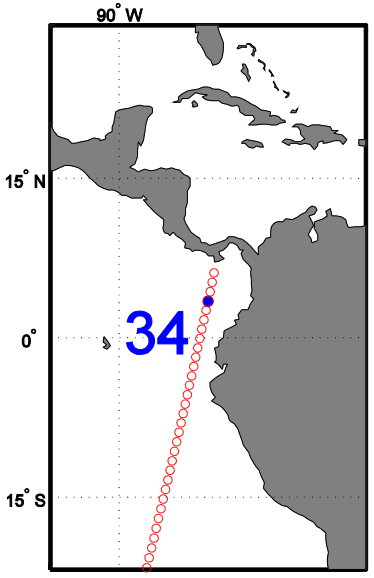
Disambiguous spectrum



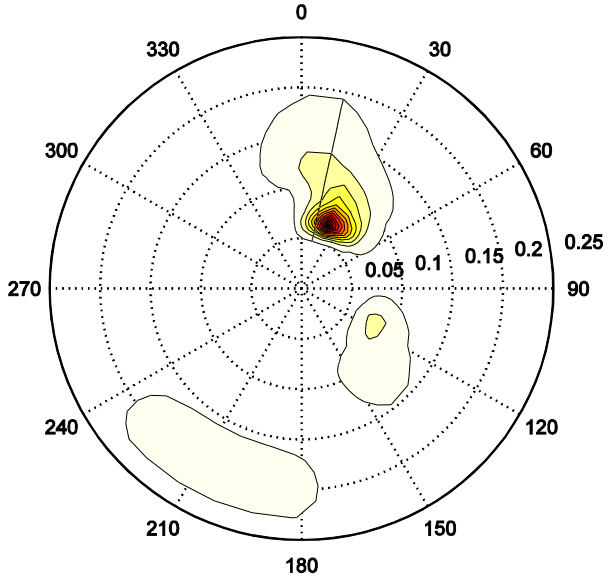
globwave spectrum



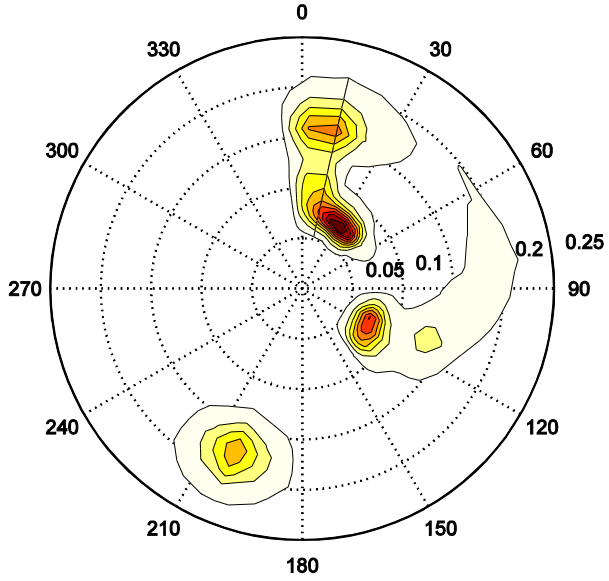
location



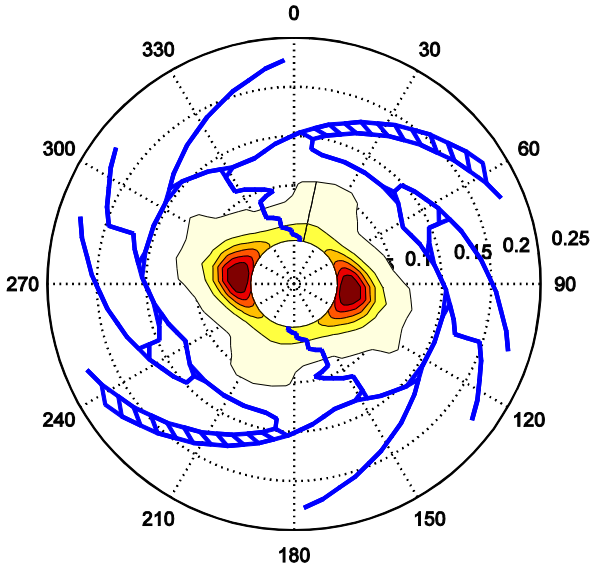
model



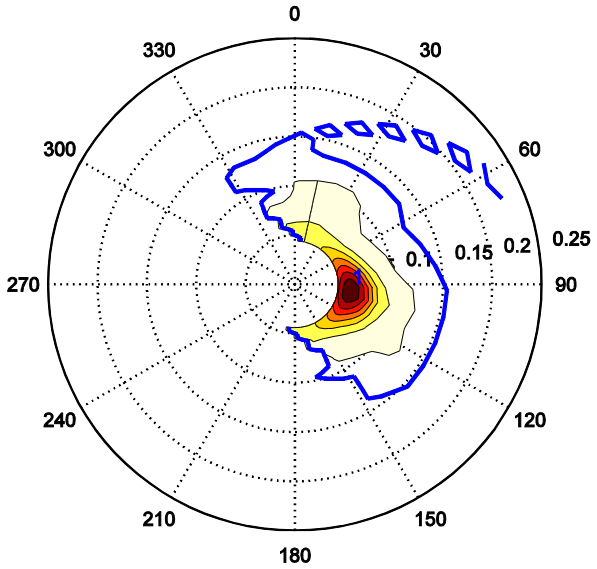
Overall spectral statistics



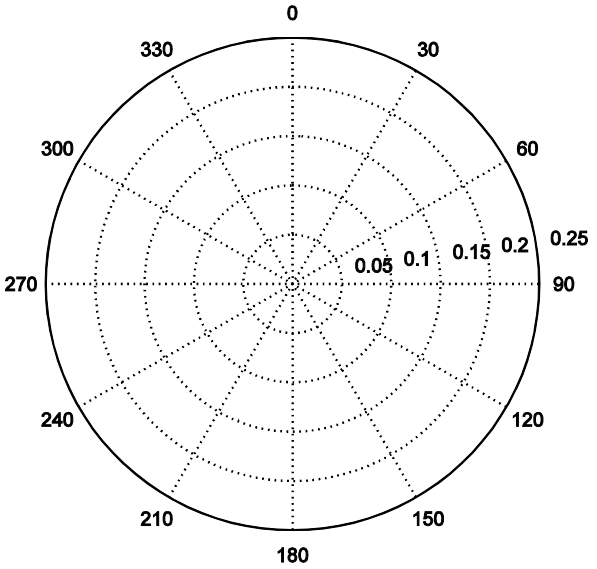
Ambiguous Spectrum



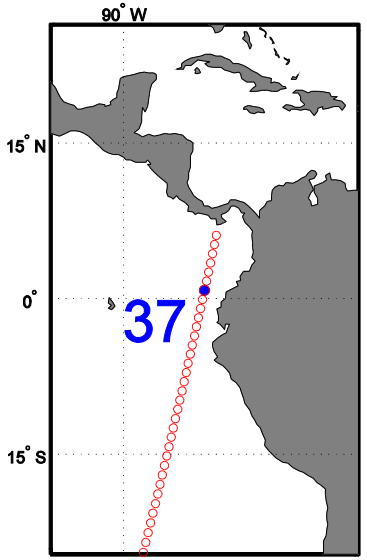
Disambiguous spectrum



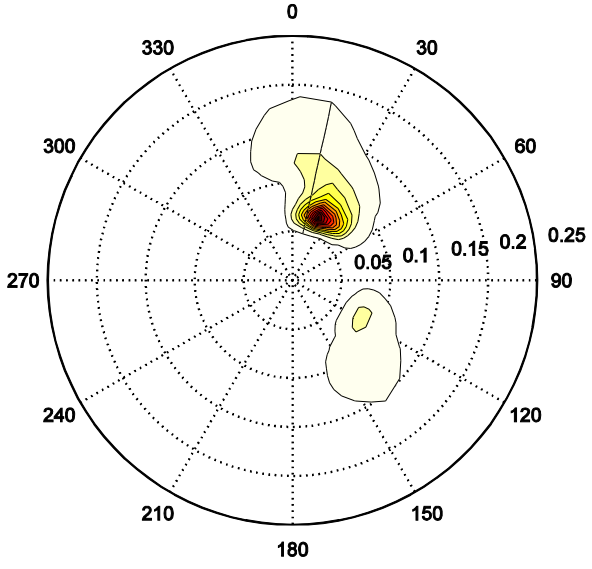
globwave spectrum



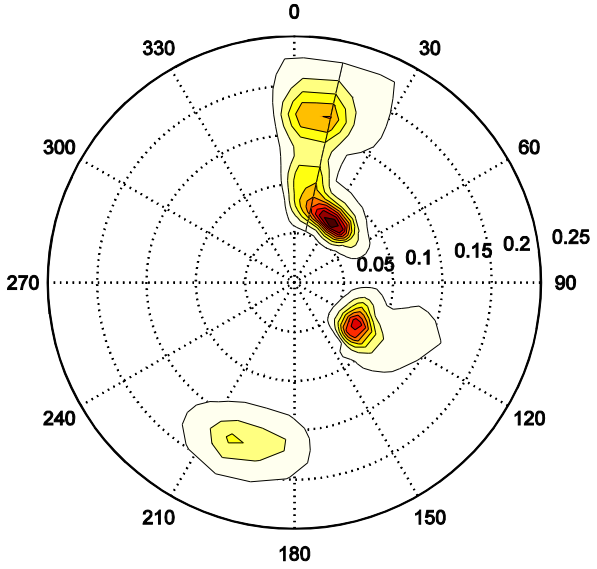
location



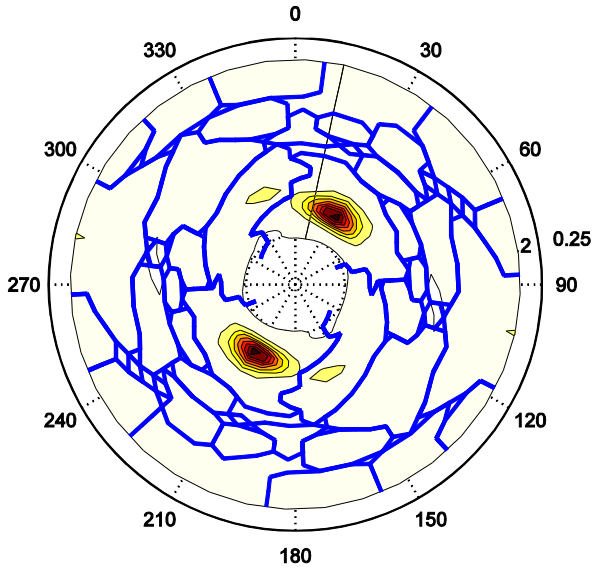
model



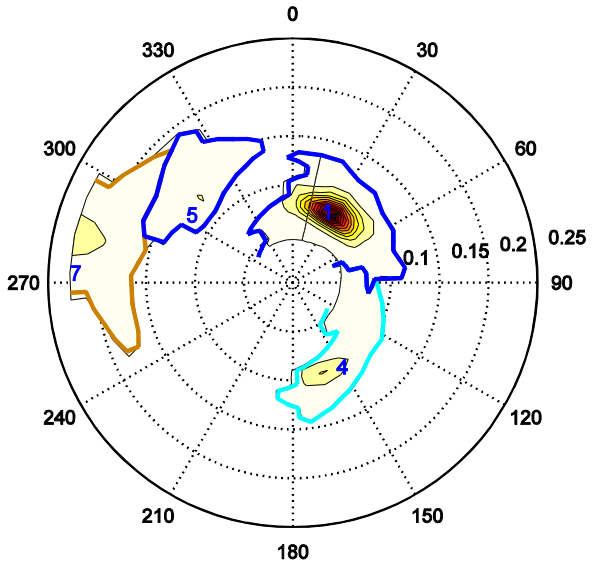
Overall spectral statistics



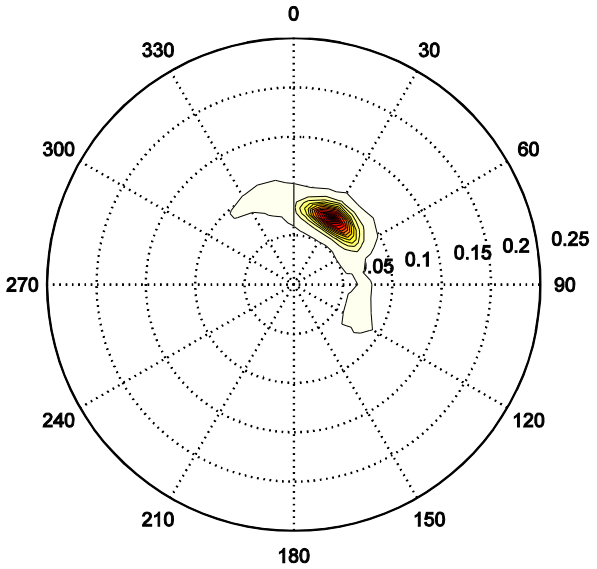
Ambiguous Spectrum



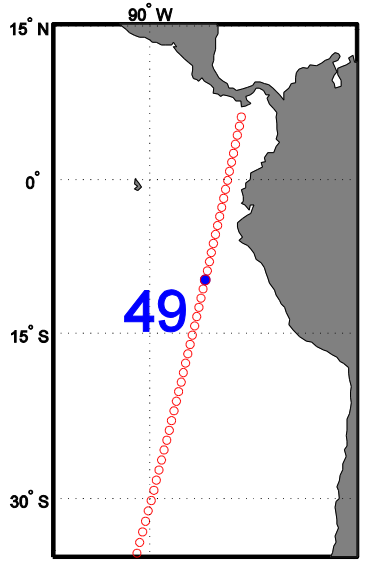
Disambiguous spectrum



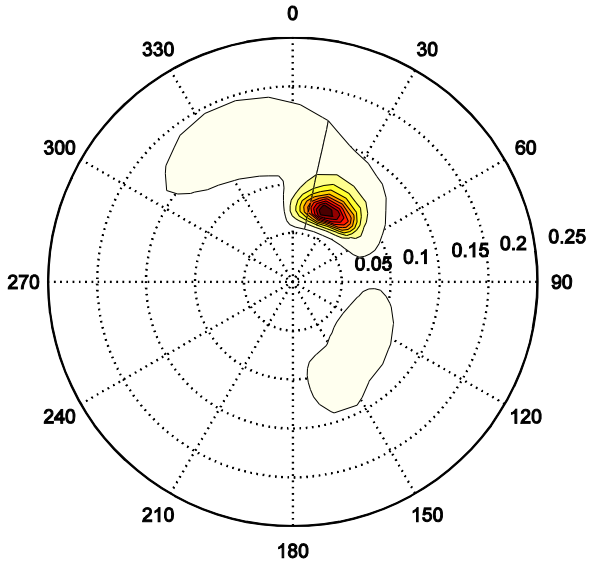
globwave spectrum



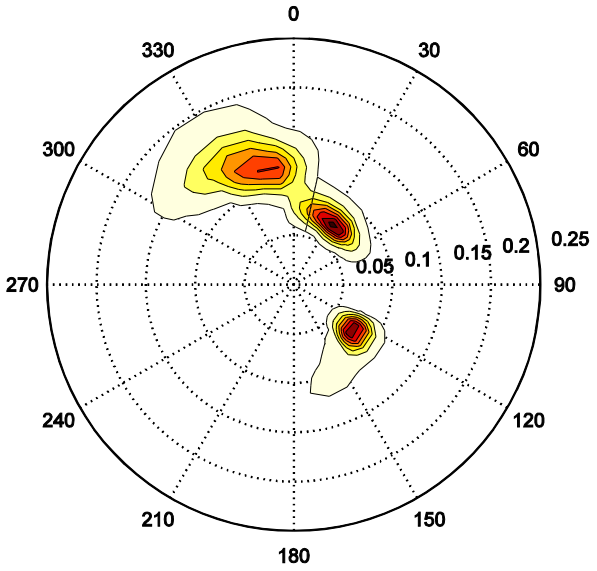
location



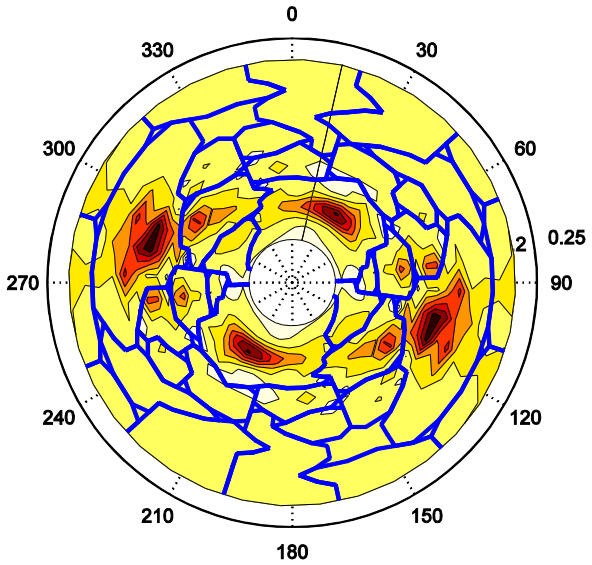
model



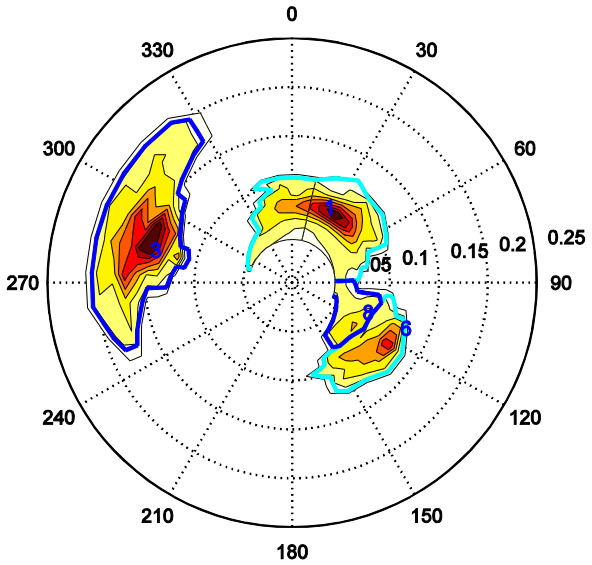
Overall spectral statistics



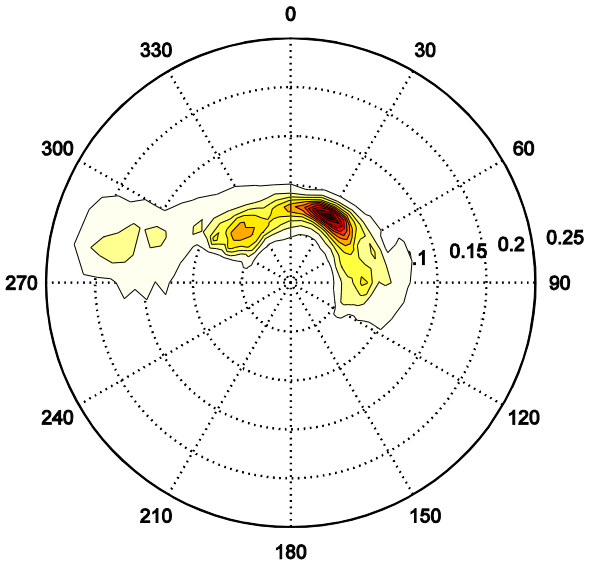
Ambiguous Spectrum



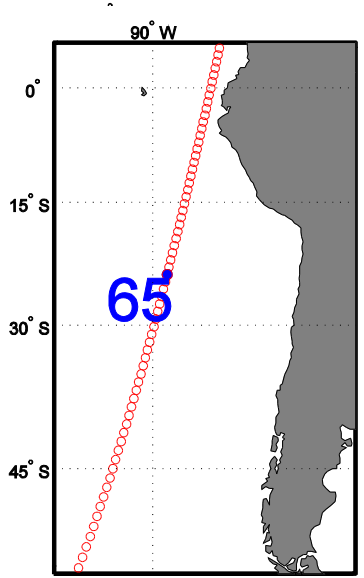
Disambiguous spectrum



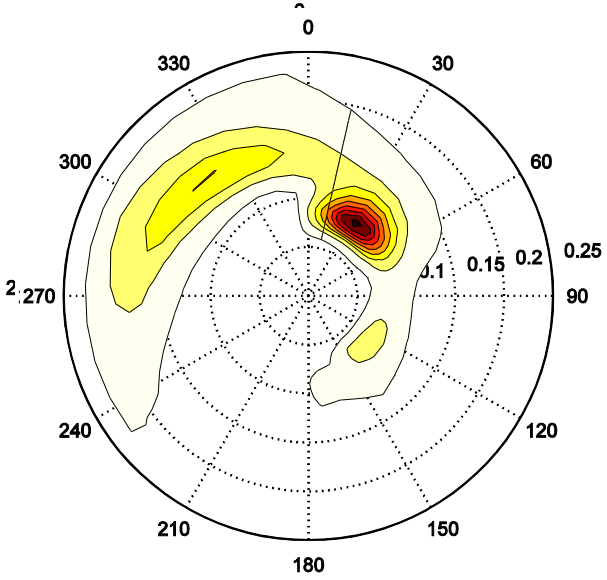
globwave spectrum



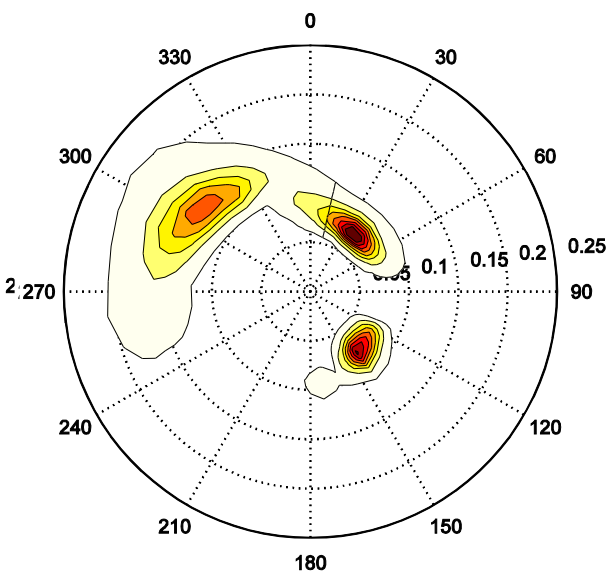
location



model



Overall spectral statistics



- The proposed algorithm solves the ambiguity problem improving the end quality of the SAR spectra (compared to previous methods such as that from GlobWave).

- The results obtained are very consistent. The added advantage is that the retrieved spectra are delivered with an associated uncertainty with quality flags parameters.

THANK YOU

FOR YOUR ATTENTION