Spatial and Temporal Tracking of Ocean Wave Systems

André van der Westhuysen

(with thanks to Jeff Hanson and Eve-Marie Devaliere)

The WAVEWATCH III Team + friends
Marine Modeling and Analysis Branch
NOAA / NWS / NCEP / EMC

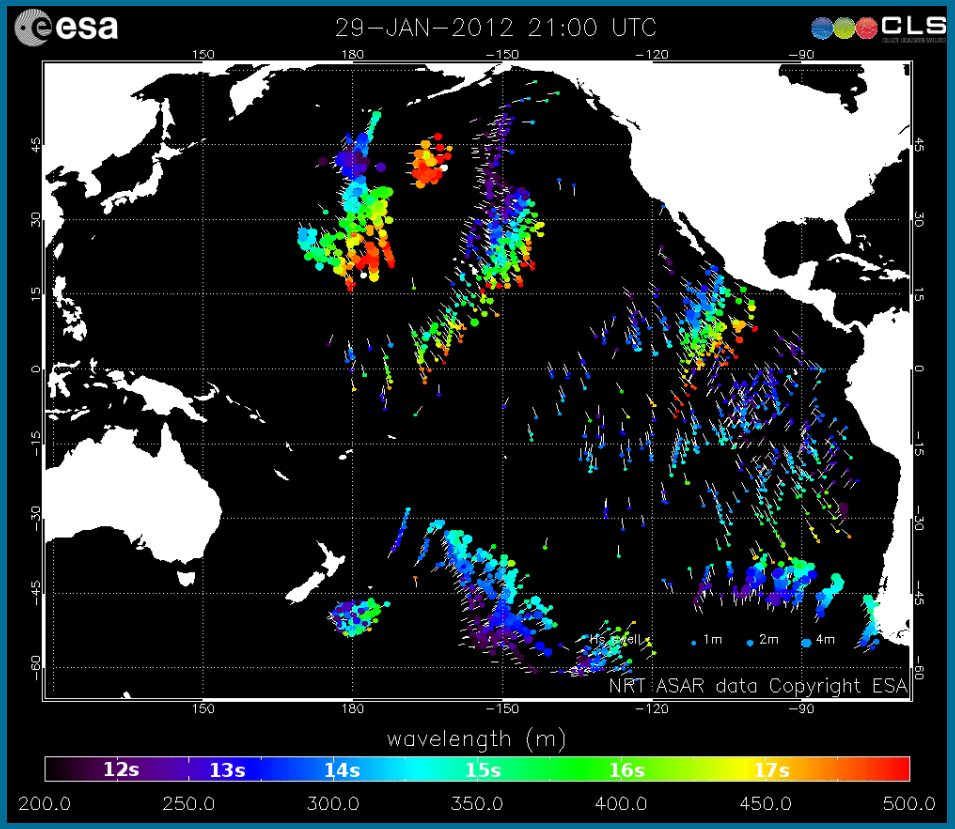
NCEP.list.WAVEWATCH@NOAA.gov
NCEP.list.waves@NOAA.gov

Covered in this lecture:

- Partitioning and tracking algorithms
- Criteria for combining and tracking sytems
- Idealized cases
- Field cases:
  - North Pacific
  - Hawaiian Islands
  - U.S. West Coast
  - WFO Los Angeles
- Conclusions and future work

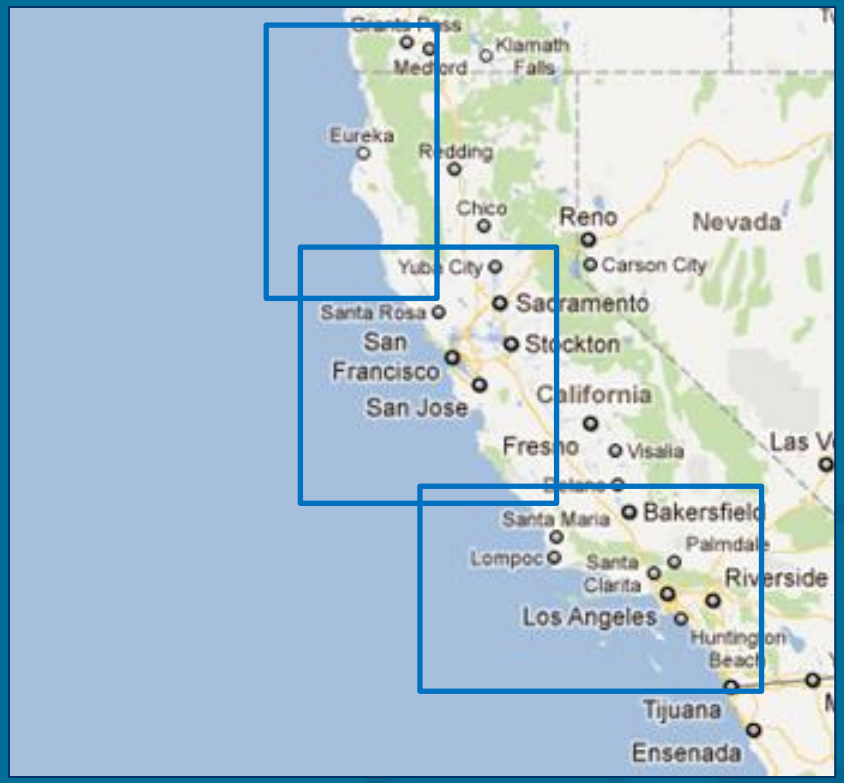
Background: Wave systems

Tracking of ASAR swell in the Pacific

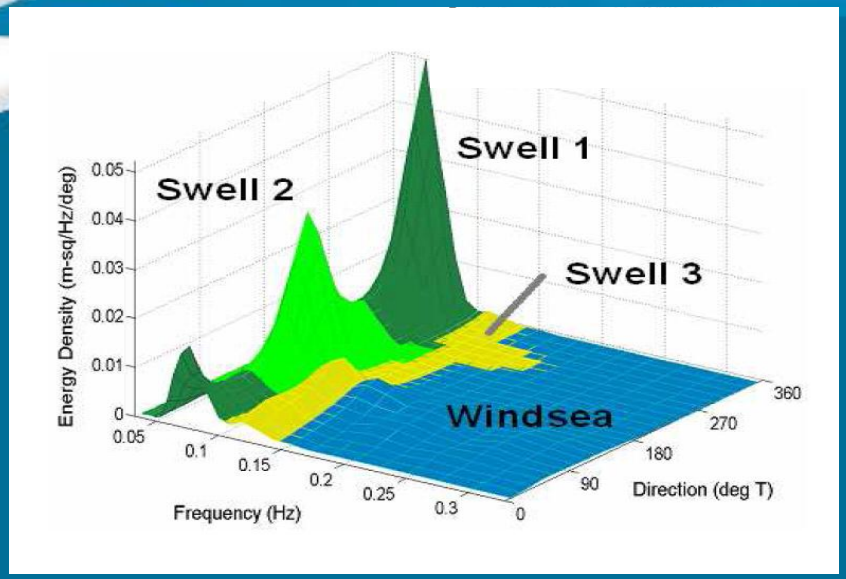


http://www.esa.int/esaEO/SEM563AATME_index_0.html

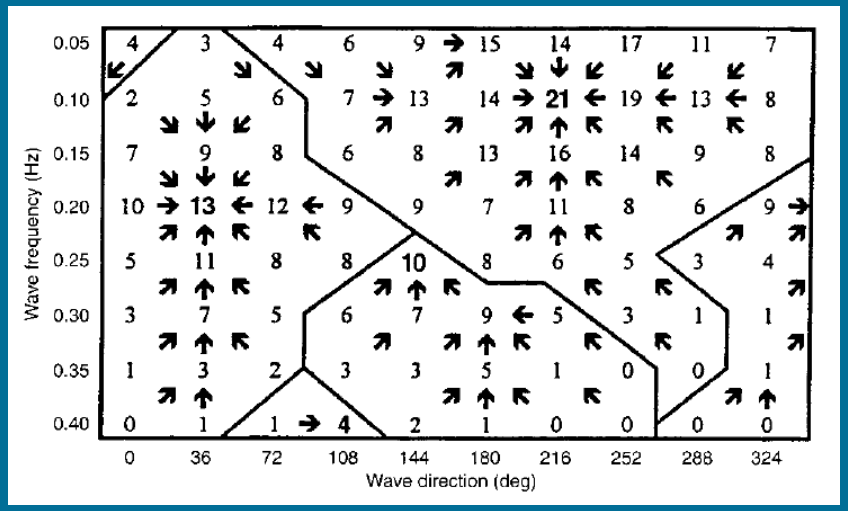
NWS coastal forecast domains



Partitioning of spectral model output

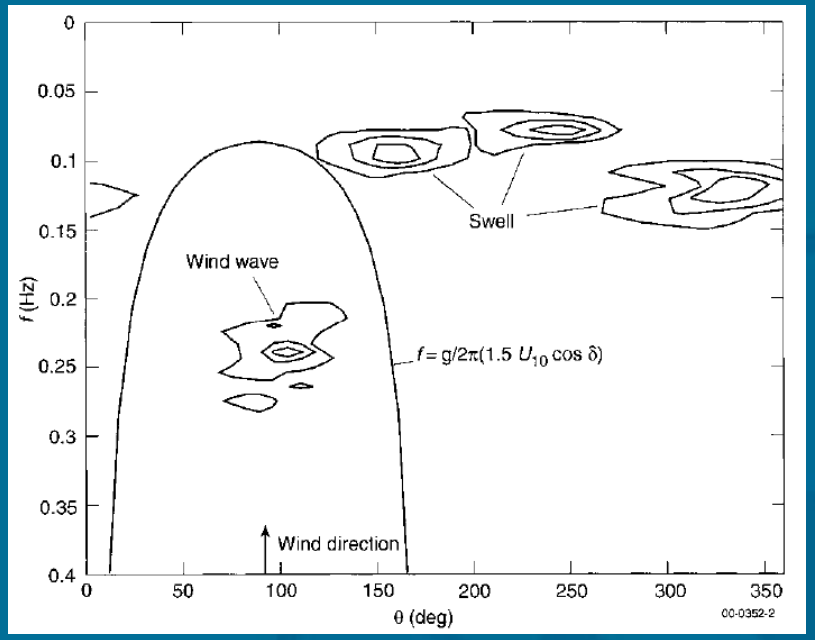


(Tracy et al. 2007)



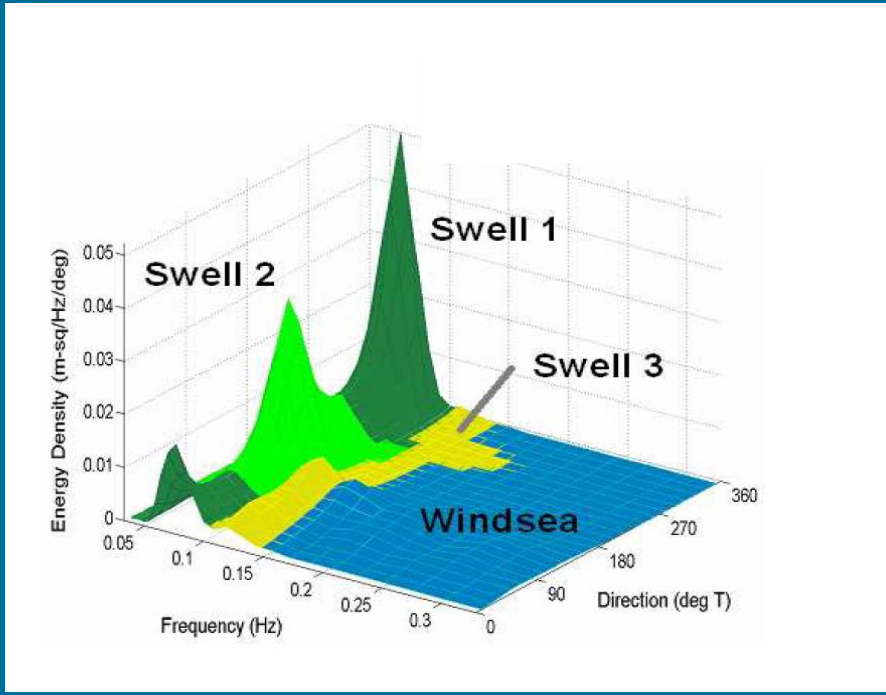
(Hanson & Phillips 2001)

Partitioning of wave spectra
- Gerling (1992)
- Hasselmann et al. (1994, 1996)
- Hanson & Phillips (2001)
- Portilla et al. (2009)

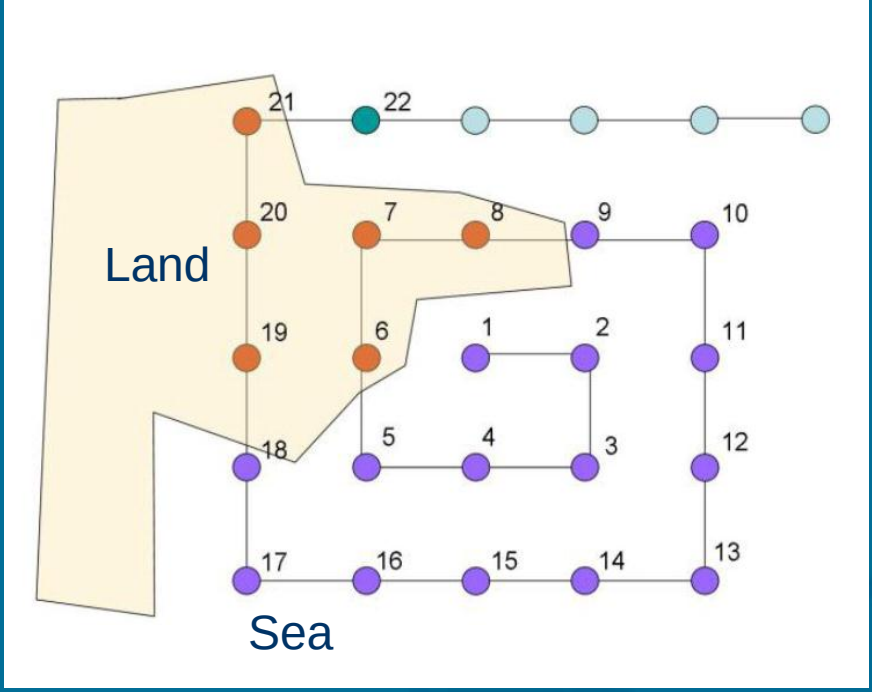


(Hanson & Phillips 2001)

Tracking of spectral model output



(Tracy et al. 2007)



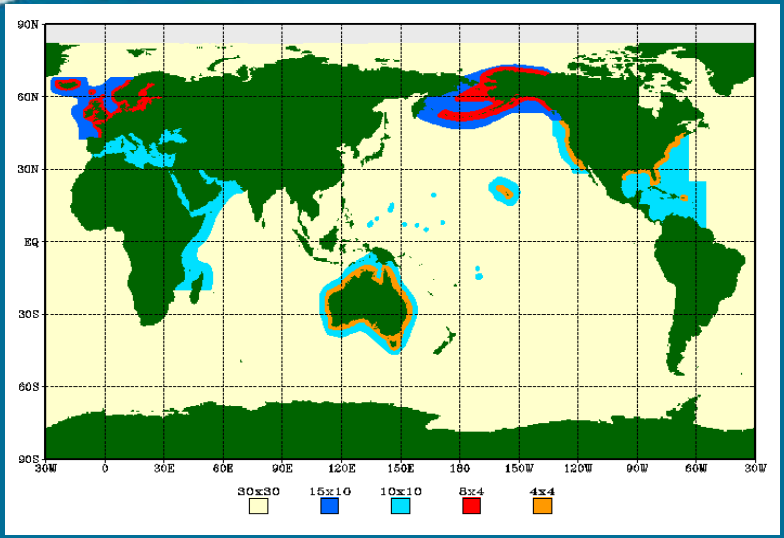
(Devaliere et al. 2009)

Correlation of partitions in space and time:

- Continuity of parameters (Voorrips et al. 1997; Hanson & Phillips 2001; Devaliere et al. 2009)
- Source identification (Aarnes & Krogstad 2001; Delpey et al. 2010)

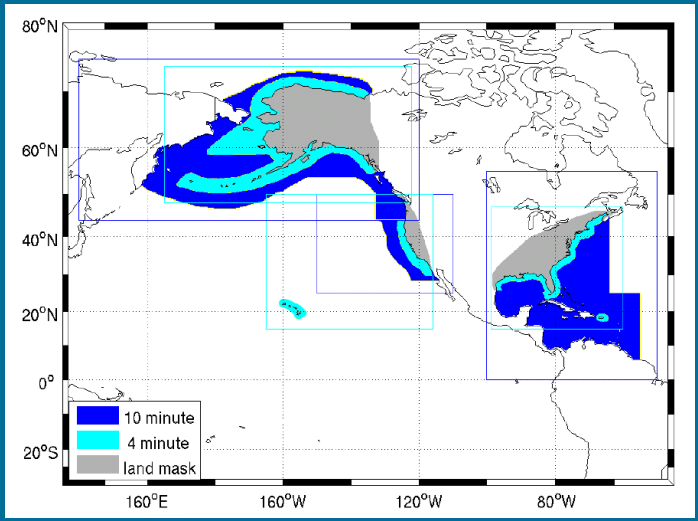
30-yr WW3 hindcast based on CFSR winds

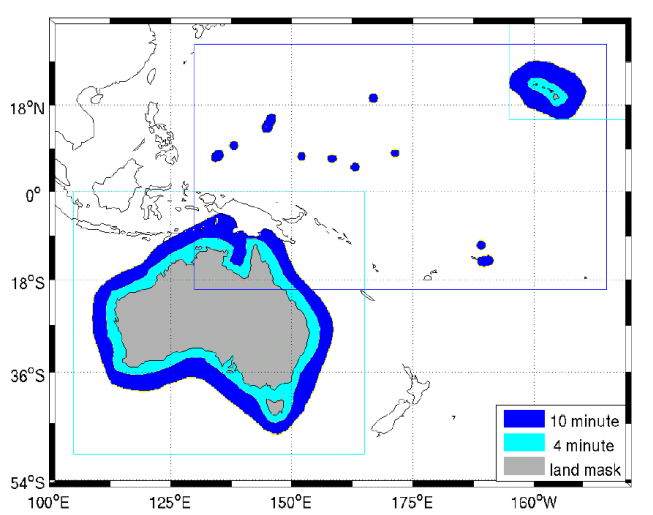
(Chawla et al. 2013)



Name	Grid label	Latitude	Longitude	Resolution (lat x lon)
Global	glo_30m	$90°S : 90°N$	$180°E : 180°W$	1/2° x 1/2°
Arctic	ao_30m	$55°N : 90°N$	$180°E : 180°W$	1/2° x 1/2°
Mid-Globe	mid_30m	$65°S : 65°N$	$180°E : 180°W$	1/2° x 1/2°
Antarctic	ac_30m	$90°S : 55°S$	$180°E : 180°W$	1/2° x 1/2°

Name	Grid label	Latitude	Longitude	Resolution (lat x lon)
East Coast US	ecg_10m	$0°N : 55°N$	$100°W : 50°W$	1/6° x 1/6°
West Coast US	wc_10m	$25°N : 50°N$	$150°W : 110°W$	1/6° x 1/6°
Alaska	ak_10m	$44°N : 75°N$	$140°E : 120°W$	1/6° x 1/4°
Pacific Isl.	pi_10m	$20°S : 30°N$	$130°E : 145°W$	1/6° x 1/6°
Australia	oz_10m	$50°S : 0°N$	$105°E : 165°E$	1/6° x 1/6°
North Sea	nsb_10m	$42°N : 75°N$	$28°W : 31°E$	1/6° x 1/4°
Mediterranean	med_10m	$30°S : 48°N$	$7°W : 43°E$	1/6° x 1/6°
NW Indian O.	nwio_10m	$20°S : 31°N$	$30°E : 70°E$	1/6° x 1/6°

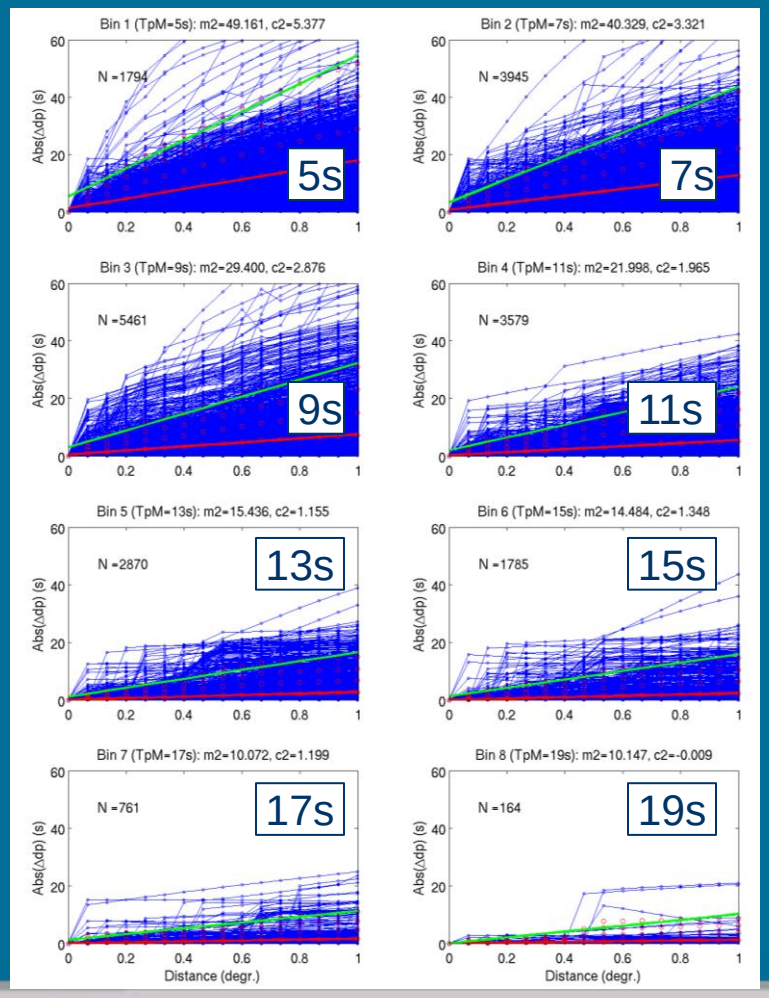




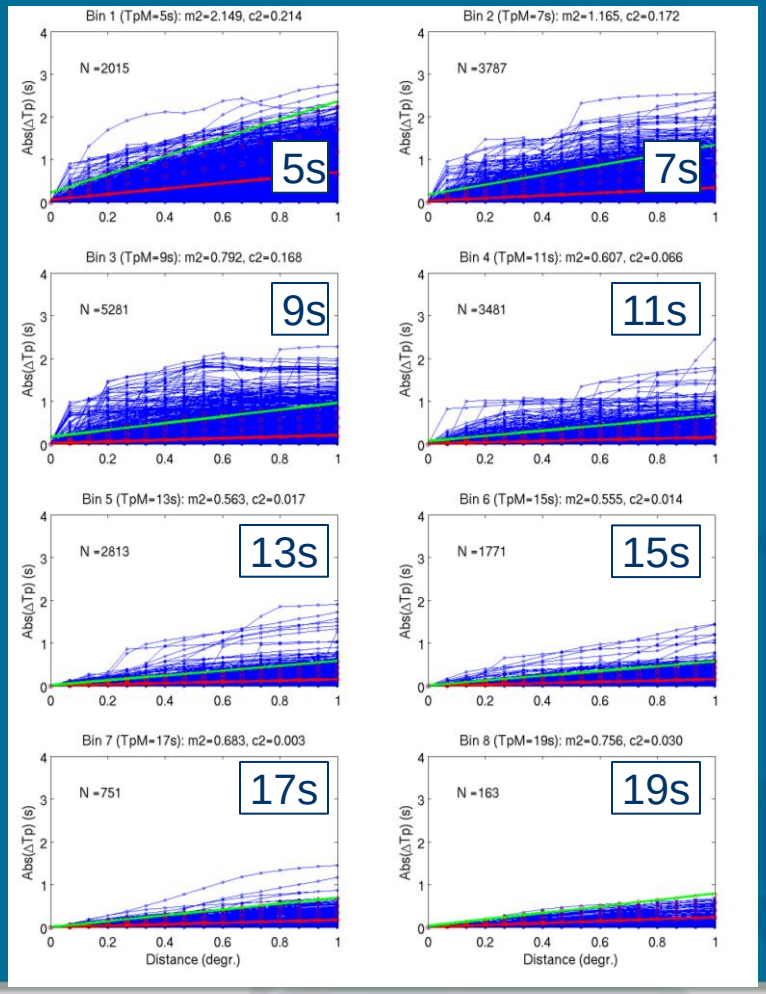
Spatial variation of DIR_p and T_p

CFSRR-WW3 4 arc-min, 3h hindcast, over 2007-2008
NDBC 46213, 46047, 41012, 41014

Dir_p



T_p



Criteria for spatial tracking

Loop 1: Linking points to systems:

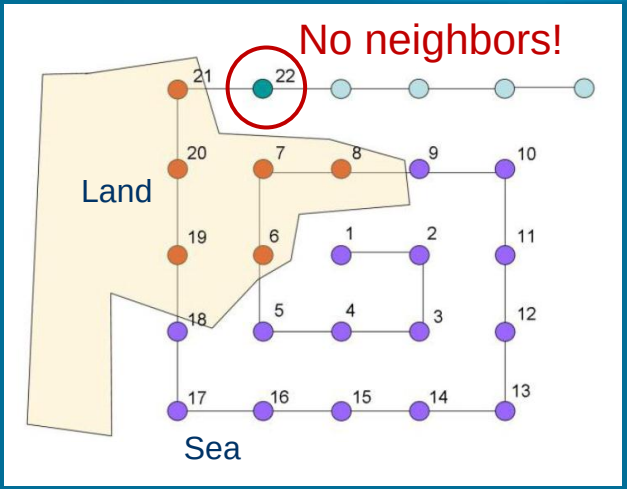
$$GoF_i = \left(\frac{T_p - \tilde{T}^n_{p,i}}{\Delta T_n}\right)^2 + \left(\frac{\theta_p - \tilde{\theta}^n_{p,i}}{\Delta \theta_n}\right)^2 + \left(\frac{H_{m0} - \tilde{H}^n_{m0,i}}{\Delta H_n}\right)^2$$

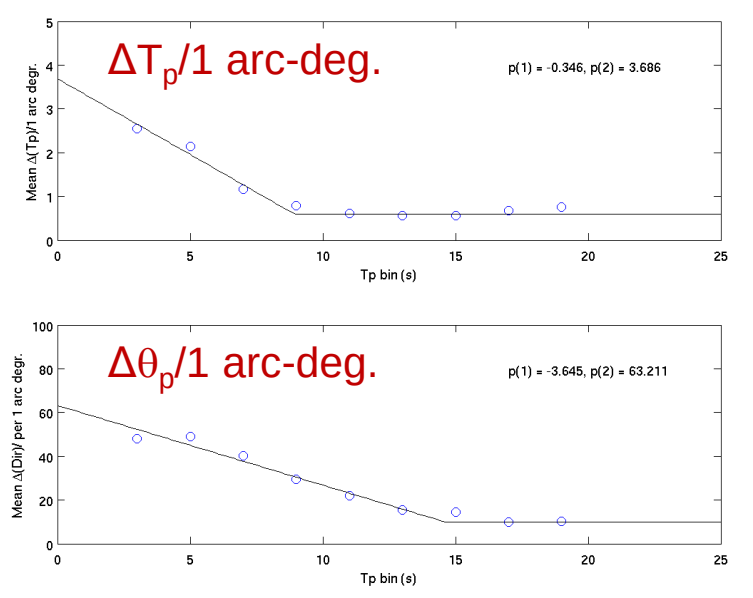
where:

$$\Delta T_n = m_1 \Delta x + \delta_T$$
$$\Delta \theta_n = m_2 \Delta x + \delta_\theta$$

$$m_1 = \max\left(-0.346\,\tilde{T}^n_{p,i} + 3.69,\ 0.6\right)$$
$$m_2 = \max\left(-3.65\,\tilde{T}^n_{p,i} + 63.2,\ 10\right)$$

and: $\delta_\theta = 10^o$, $\delta_T = 1$





Loop 2: Combining systems:

Combine if system neighbors differ by less than ΔT_n and $\Delta\theta_n$, with Δx = 1 arc-deg

3 Criteria for temporal tracking

1) Mean period over system

$$\Delta T_s = m_1 \Delta x + \delta_T \quad , \quad \Delta x = 1 \text{ arc deg}$$

$$m_1 = \max\left(-0.346\,\tilde{T}^{s}_{p,i} + 3.69,\, 0.6\right)$$

Setting: δ_T = 1 s

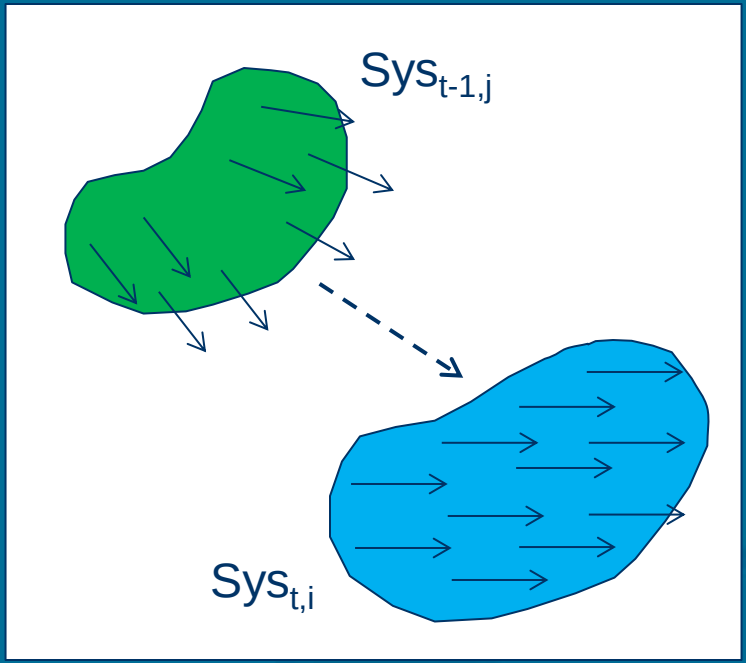
2) Mean direction over system

$$\Delta \theta_s = m_2 \Delta x + \delta_\theta \quad , \quad \Delta x = 1 \text{ arc deg}$$

$$m_2 = \max\left(-3.65\,\tilde{T}^{s}_{p,i} + 63.2,\, 10\right)$$

Setting: δ_θ = 10°

3) Spatial overlap of systems: $\cap_{i,j}$

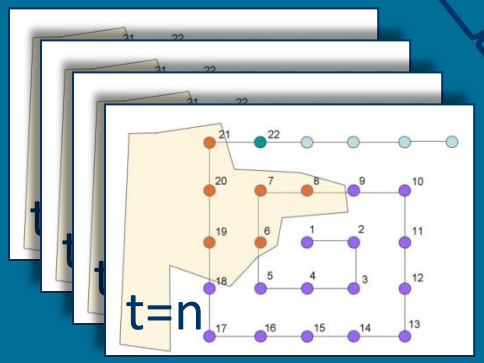


$$GoF_{i,j} = \left(\frac{\tilde{T}^{s}_{p,t,i} - \tilde{T}^{s}_{p,t-1,j}}{\Delta T_s}\right)^2 + \left(\frac{\tilde{\theta}^{s}_{p,t,i} - \tilde{\theta}^{s}_{p,t-1,j}}{\Delta \theta_s}\right)^2 + \left(\frac{N_{t-1,j} - \cap_{i,j}}{0.5 N_{t-1,j}}\right)^2$$

Program flow

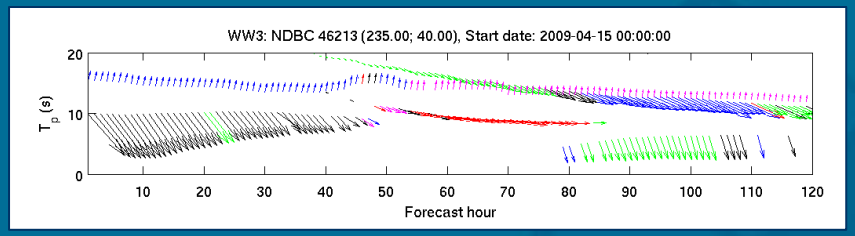
ww3_systrk (main program)

- waveTracking (read spectral partition input)
  - spiralTrack



Parallel region

  - timeTracking

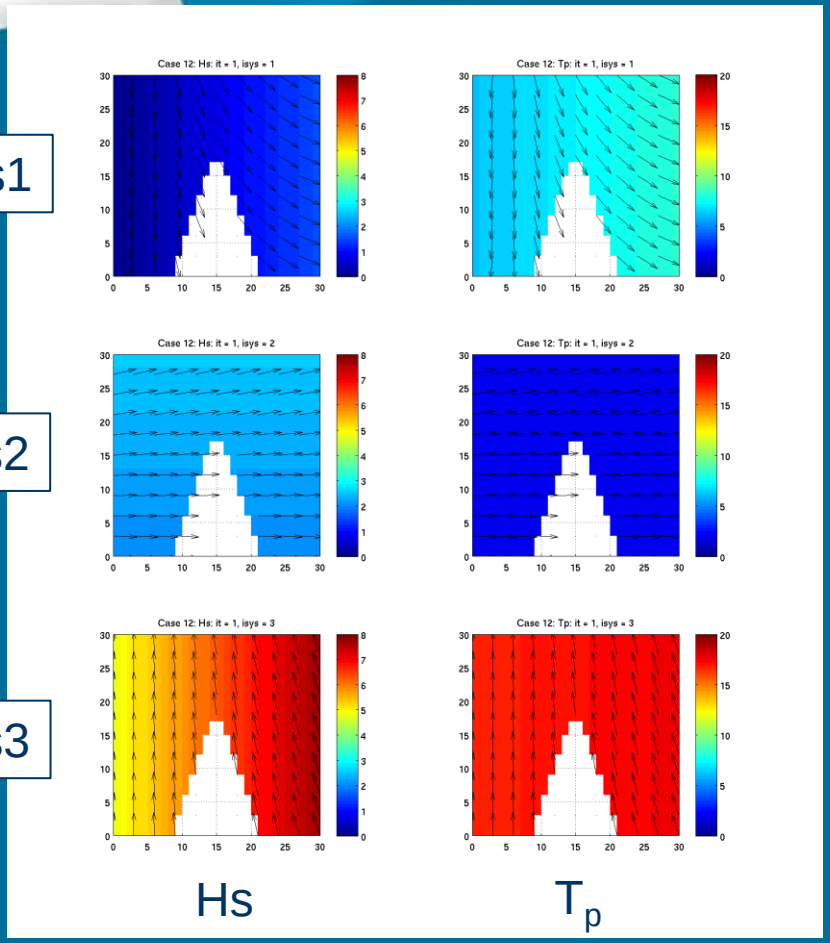


Idealized cases (wedge, “plus” island)

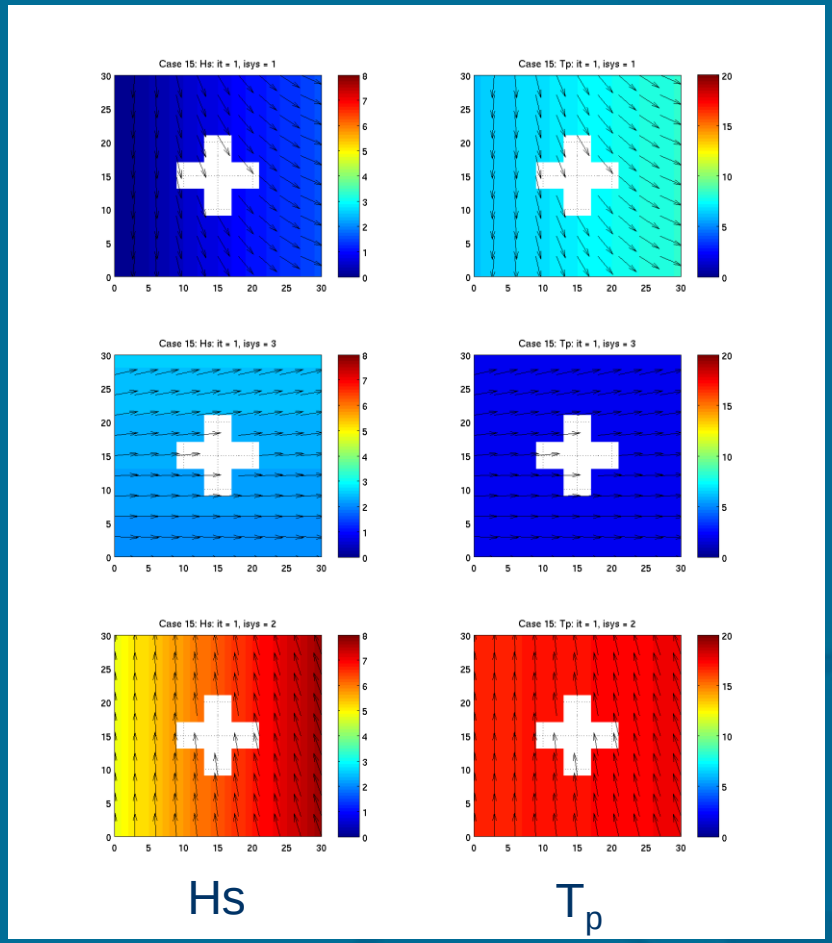
Sys1

Sys2

Sys3

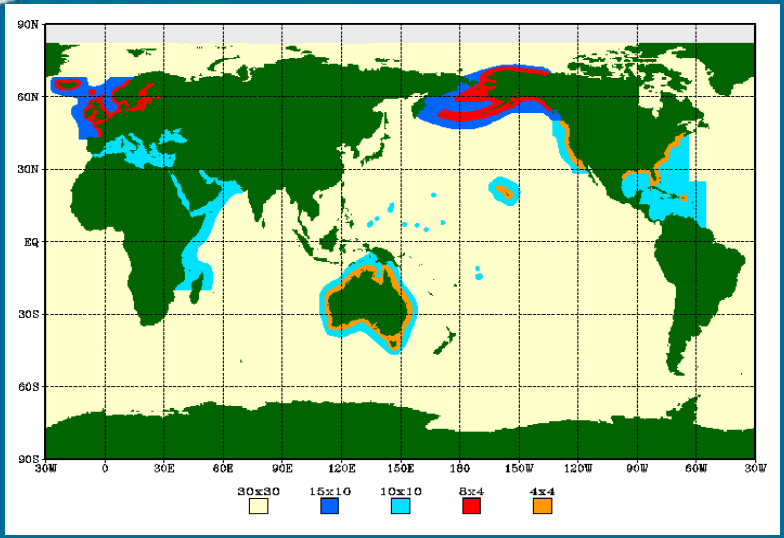


Hs T_p



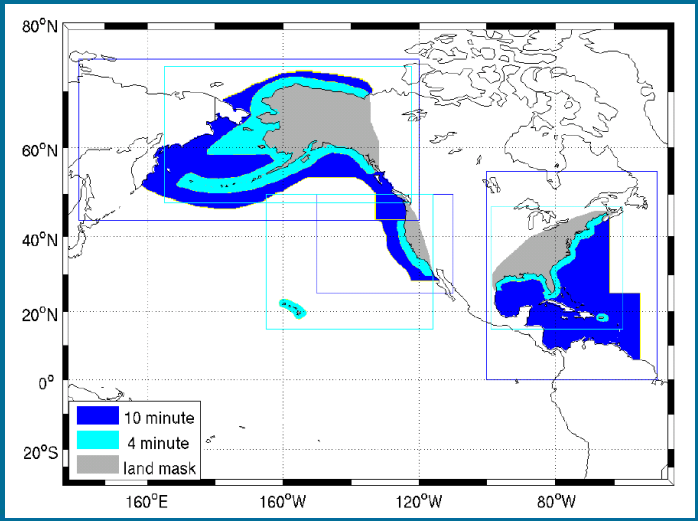
Hs T_p

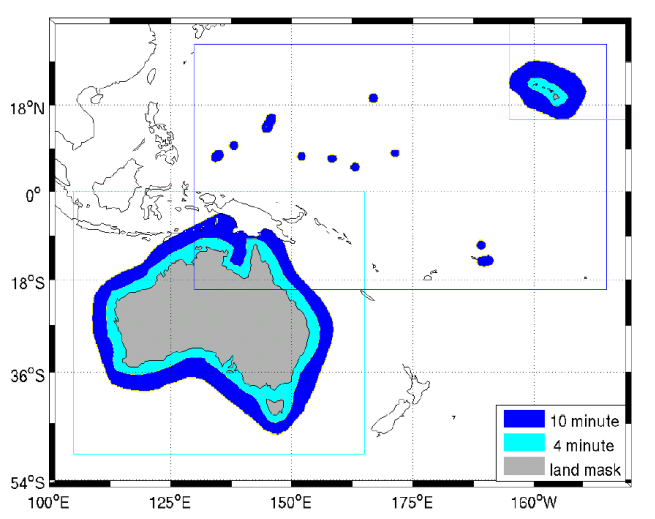
30-yr WW3 hindcast based on CFSR winds



Name	Grid label	Latitude	Longitude	Resolution (lat x lon)
Global	glo_30m	$90°S : 90°N$	$180°E : 180°W$	1/2° x 1/2°
Arctic	ao_30m	$55°N : 90°N$	$180°E : 180°W$	1/2° x 1/2°
Mid-Globe	mid_30m	$65°S : 65°N$	$180°E : 180°W$	1/2° x 1/2°
Antarctic	ac_30m	$90°S : 55°S$	$180°E : 180°W$	1/2° x 1/2°

Name	Grid label	Latitude	Longitude	Resolution (lat x lon)
East Coast US	ecg_10m	$0°N : 55°N$	$100°W : 50°W$	1/6° x 1/6°
West Coast US	wc_10m	$25°N : 50°N$	$150°W : 110°W$	1/6° x 1/6°
Alaska	ak_10m	$44°N : 75°N$	$140°E : 120°W$	1/6° x 1/4°
Pacific Isl.	pi_10m	$20°S : 30°N$	$130°E : 145°W$	1/6° x 1/6°
Australia	oz_10m	$50°S : 0°N$	$105°E : 165°E$	1/6° x 1/6°
North Sea	nsb_10m	$42°N : 75°N$	$28°W : 31°E$	1/6° x 1/4°
Mediterranean	med_10m	$30°S : 48°N$	$7°W : 43°E$	1/6° x 1/6°
NW Indian O.	nwio_10m	$20°S : 31°N$	$30°E : 70°E$	1/6° x 1/6°

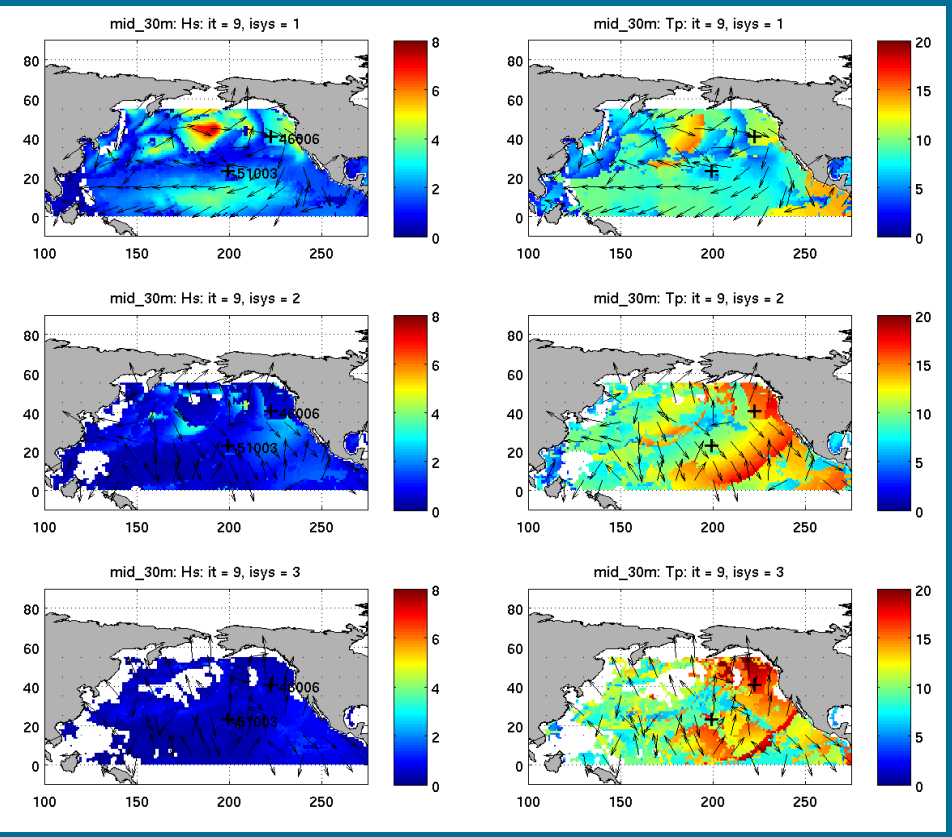




North Pacific, 30 arc-min grid

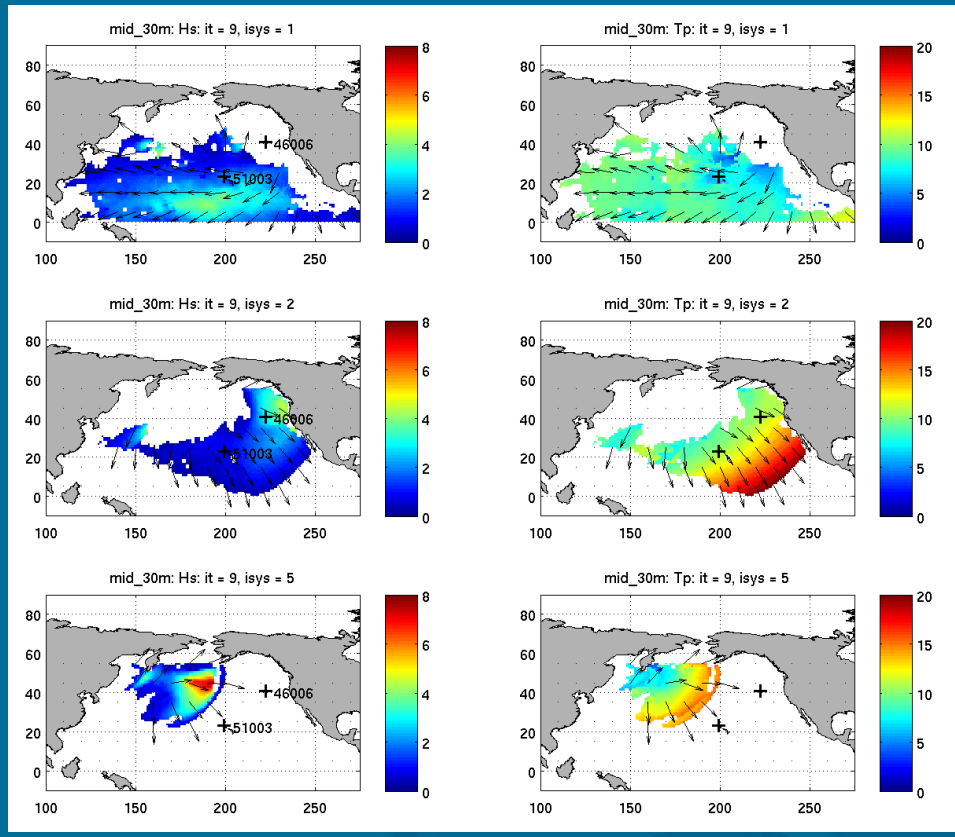
14 April 2009, 10:00

Raw partitioned data



Hs Tp

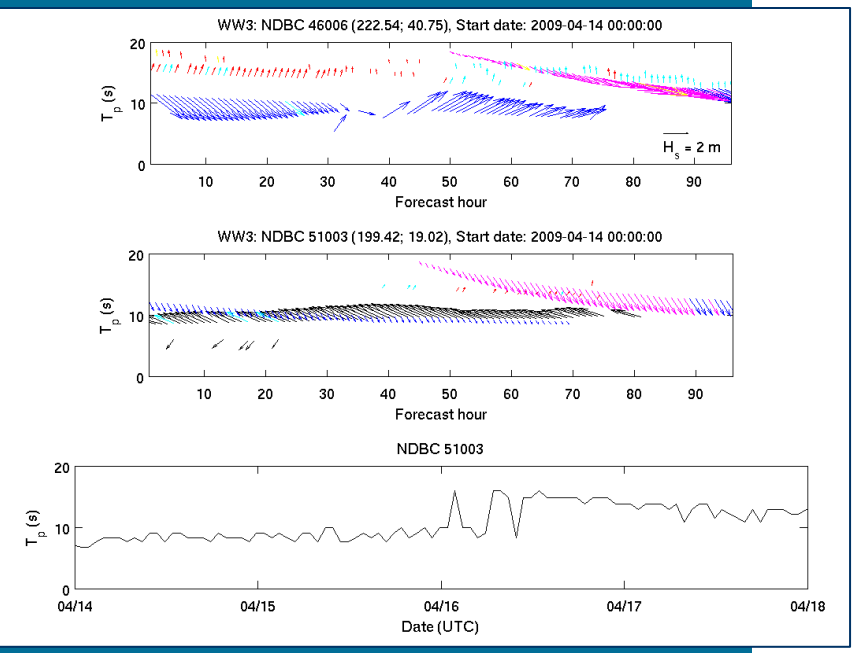
Spatially tracked systems

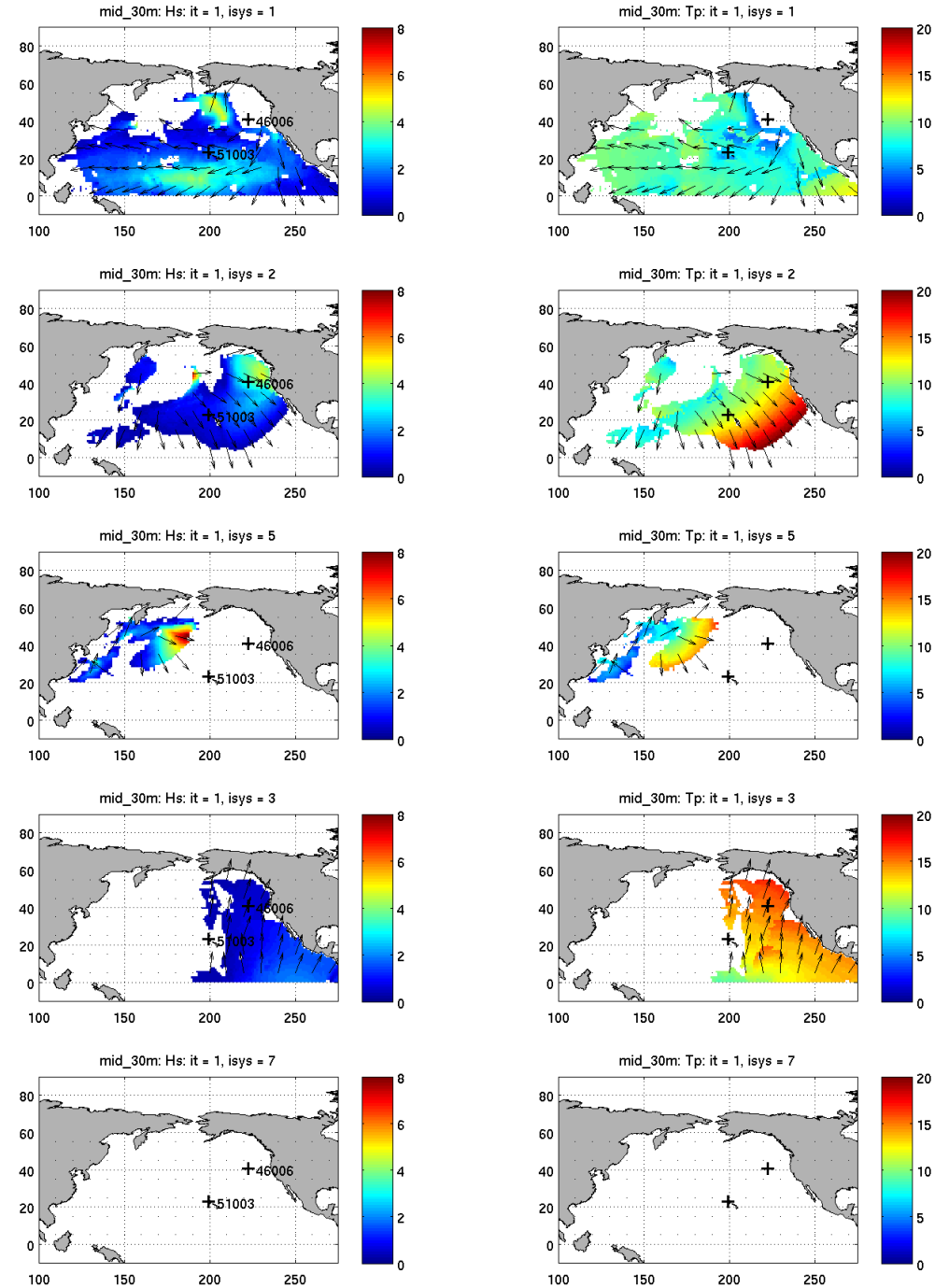


Hs Tp

North Pacific, 30 arc-min grid

14 -18 April 2009

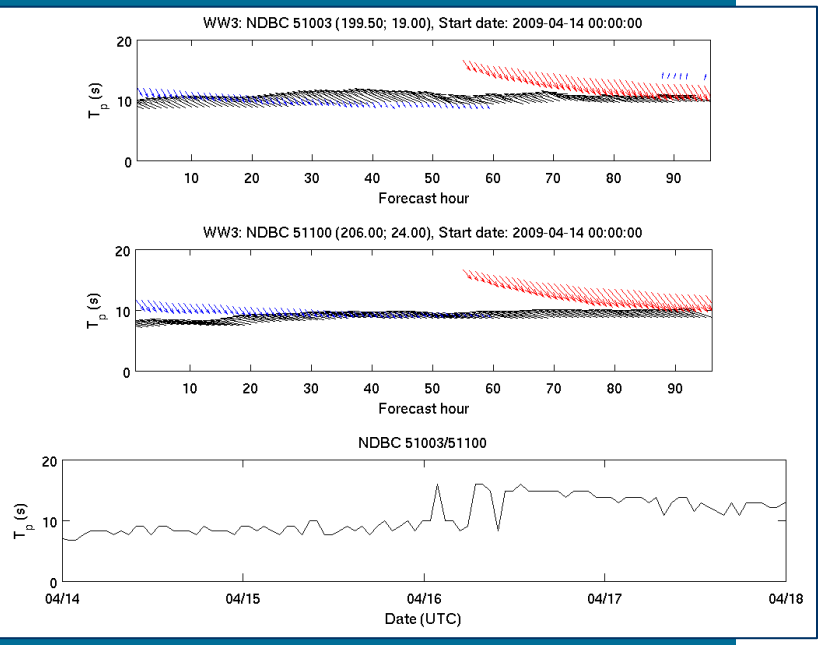


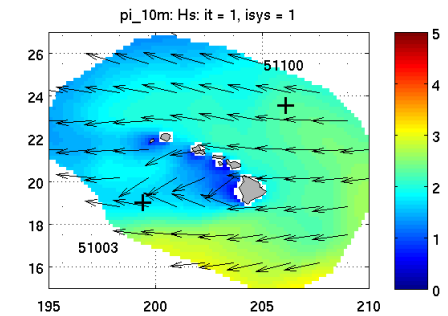


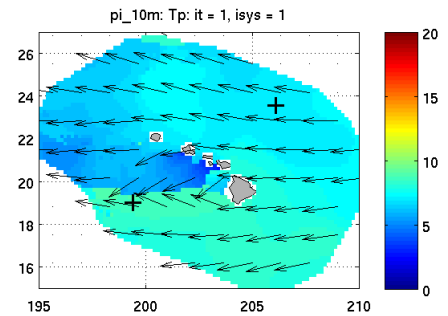
Sys 1 Sys 2 Sys 3 Sys 4 Sys 5 Sys 6

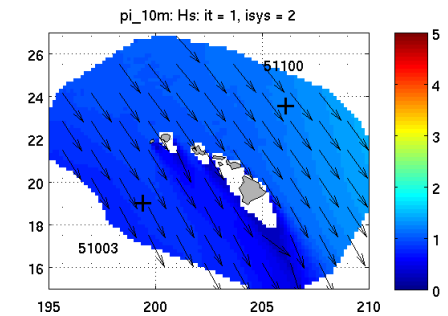
Hawaiian Islands, 10 arc-min grid

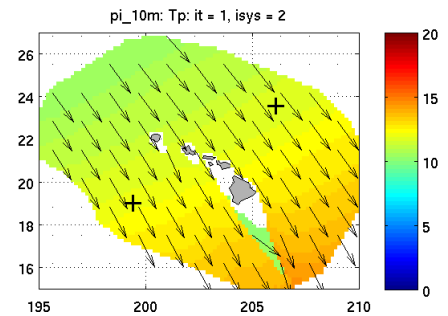
14 -18 April 2009

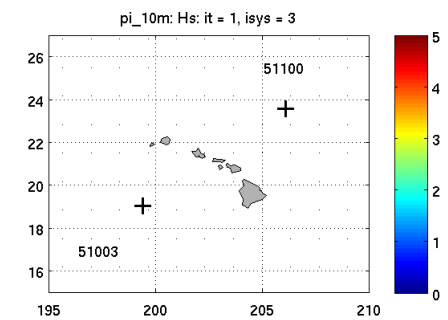


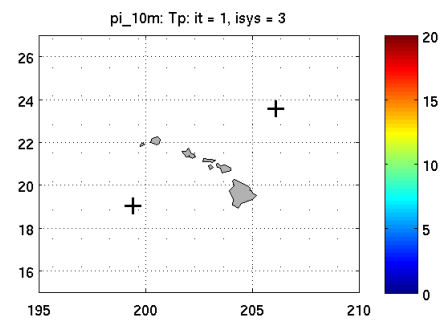


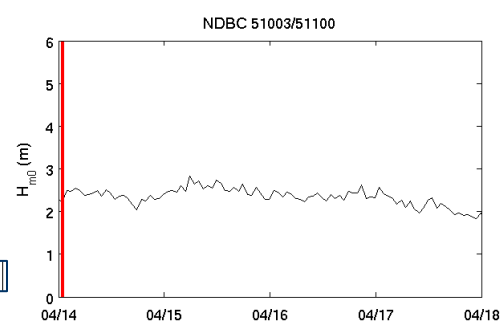


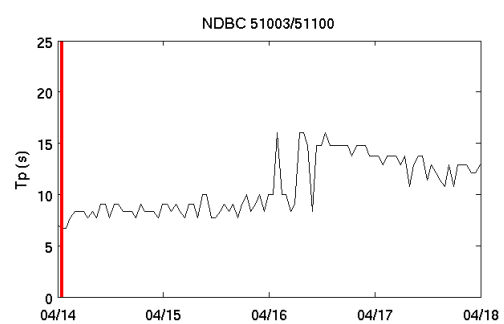








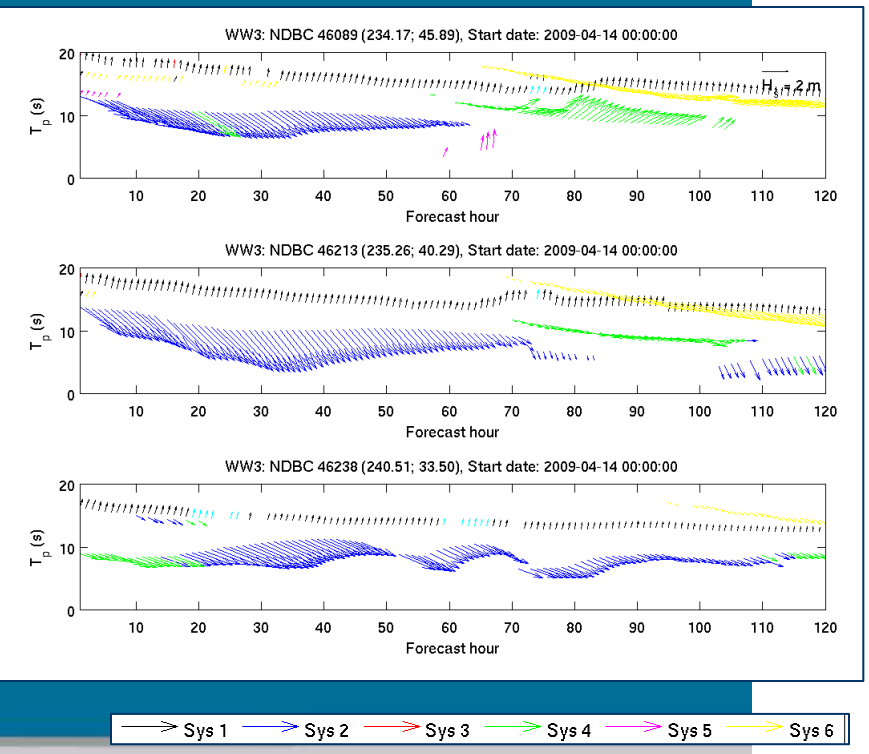


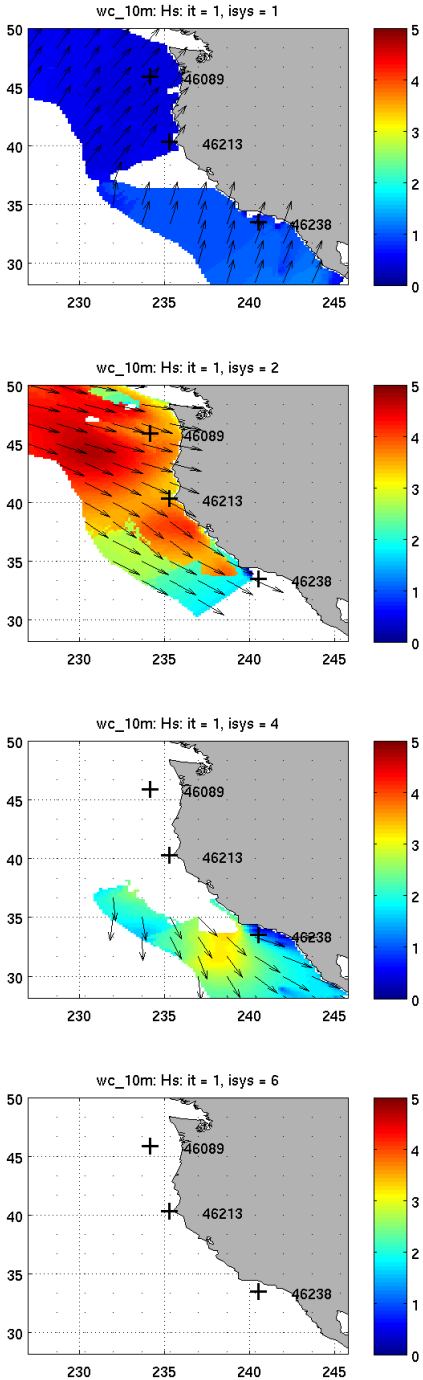


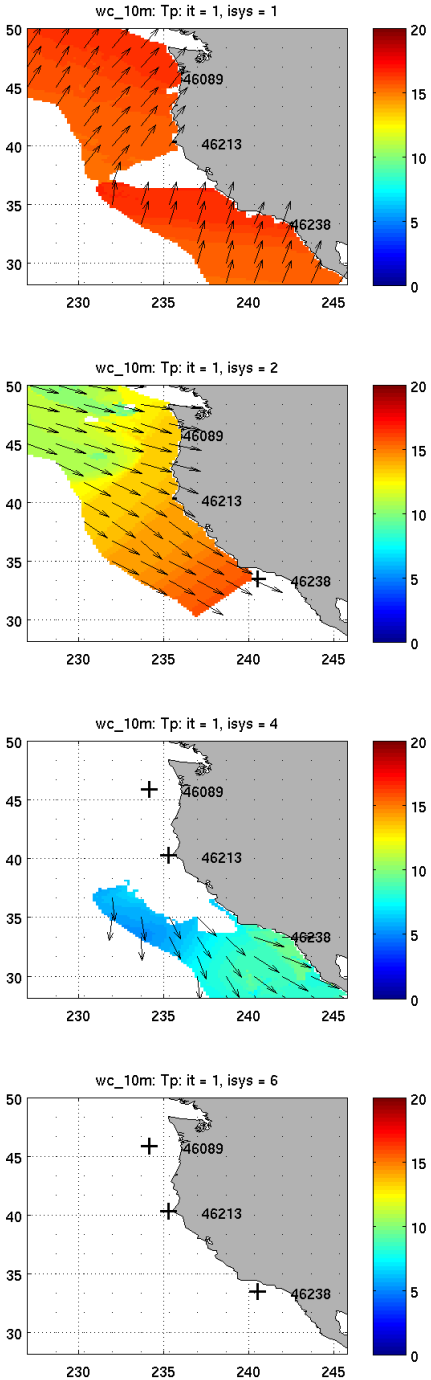
Sys 1 Sys 2 Sys 3 Sys 4 Sys 5 Sys 6

U.S. West Coast, 10 arc-min grid

14 -19 April 2009

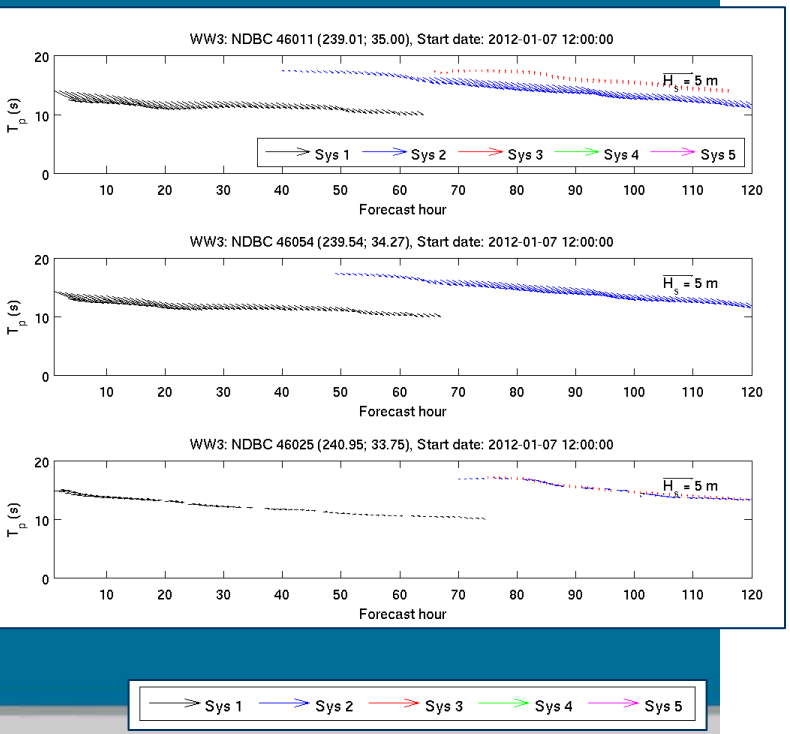


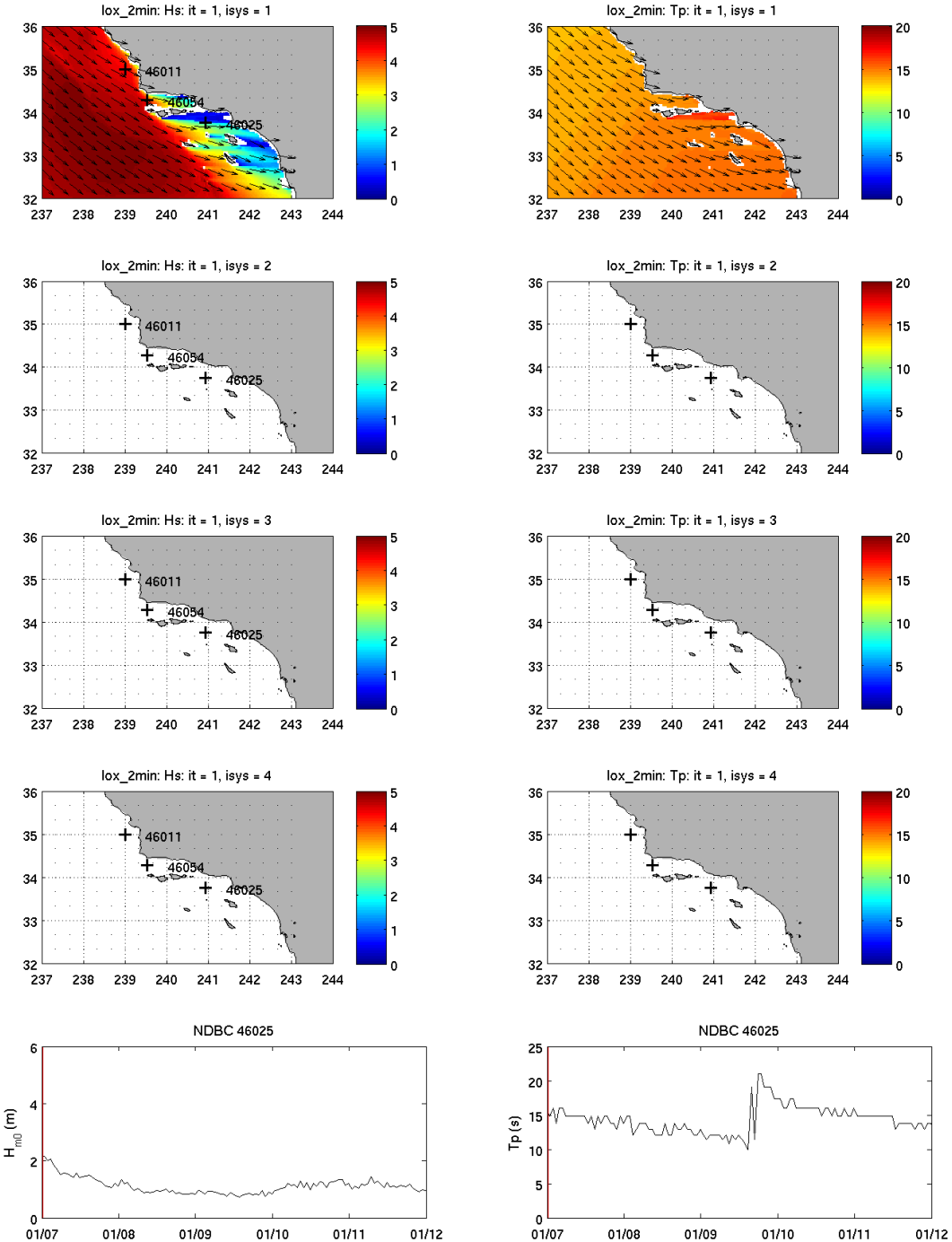




WFO Oxnard, 2 arc-min grid

7-12 Jan 2012





Conclusions & Future work

1. Spatial and temporal tracking post-processing available as WW3 subprogram ww3_systrk (see Van der Westhuysen et al. 2013).
2. Spatial variation of T_p and Dir_p determined from 2 years of CFSRR-WW3 wave climate data.
3. Verified for idealized cases and field cases at various scales (30-yr CFSRR-WW3 wave climate, WFO domains).
4. *Future*: Depth dependence in shallow water?
5. *Future*: Extension to unstructured grids

References

Aarnes, J.E, and H.E. Krogstad, 2001. Partitioning sequences for the dissection of directional ocean wave spectra: A review, technical report, SINTEF Appl. Math., Oslo.

Chawla, A., D.M. Spindler, H.L. Tolman, 2013. Validation of a thirty year wave hindcast using the Climate Forecast System Reanalysis Winds. Ocean Modelling, in press.

Delpey, M.T., F. Ardhuin, F. Collard and B. Chapron, 2010. Space-time structure of long ocean swell fields. J. Geophys. Res. 115, C12037, doi:10.1029/2009JC005885.

Devaliere, E.-M, J.L Hanson and R.A. Luettich, Jr., 2009. Spatial tracking of numerical wave model output using a spiral tracking search algorithm, Proc. 2009 WRI World Congress on Computer Science and Information Engineering, Los Angeles, CA, Vol. 2, 404–408.

Gerling, T.W., 1992. Partitioning sequences and arrays of directional ocean wave spectra into component wave systems. J. Atmos. Oceanic Technol., 9, 444–458.

Hasselmann, S., K. Hasselmann, and C. Bruning, 1994. Extraction of wave spectra from SAR image spectra. Dynamics and Modelling of Ocean Waves, G. J. Komen et al., Eds., Cambridge University Press, 391–401.

Hasselmann, S., C. Bruning, and K. Hasselmann, 1996. An improved algorithm for the retrieval of ocean wave spectra from synthetic aperture radar image spectra, J. Geophys. Res., 101, 16,615–16,629.

Hanson, J.L. and O.M. Phillips, 2001. Automated analysis of ocean surface directional wave spectra. J. Atmos. and Ocean Tech., Vol. 18, 277–293.

Portilla, J., F. J. Ocampo-Torres and J. Monbaliu, 2009. Spectral partitioning and identification of wind sea and swell, J. Atmos. and Ocean Tech., Vol. 26, 107–122.

Tracy, B, E.-M. Devaliere, J.L. Hanson, T. Nicolini and H.L. Tolman, 2007. Wind sea and swell delineation for numerical wave modeling, Proc. 10th Int. Workshop on Wave Hindcasting and Forecasting, Paper P12.

Voorrips, A.C., V.K. Makin, and S. Hasselmann, 1997. Assimilation of wave spectra from pitch-and-roll buoys in a North Sea wave model. J. Geophys. Res. 102, 5829–5849.

Van der Westhuysen, A.J., J. Hanson and E.-M. Devaliere, 2013. Spatial and temporal tracking of wave fields from ocean basin scales to coastal waters. J. Atmos. Oceanic Technol., in review.