A two-scale approximation for wave-wave Interactions in operational wave forecast models

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What are the objectives of the project?

1. New wave model using new formulations for efficient quadruplet (nonlinear) wave-wave interactions representation
2. Tests for issues regarding wave transitions: waves and swell, turning winds, shallow water…
3. Tests for real North Atlantic storms

➢ **1:** New wave model using new efficient formulations for nonlinear wave physics.

- ➢ Two-Scale Approximation (TSA)
- ➢ fetch-limited growth and TSA characteristics
- ➢ example of hurricane Juan (2003)

Resio, D., and Perrie, W. 2008: A two-scale approximation for efficient representation of nonlinear energy transfers in a wind wave spectrum. Part 1: Theoretical Development. *J. Phys. Oceanogr.* 38: 2801-2816.

Perrie, W., and Resio, D., 2009: A two-scale approximation for efficient representation of nonlinear energy transfers in a wind wave spectrum. Part 2 Application to observed wave spectra. *J. Phys. Oceanogr.* 39: 2451 – 2476.

Resio, D., C. Long and W. Perrie, 2011: The effect of nonlinear fluxes on spectral shape and energy source-sink balances in wave generation. J. Phys. Oceanography. Vol. 41, 782-801.

Perrie, W., B. Toulany, D. Resio, A. Roland, J.-P. Auclair, 2013: A two-scale approximation for wave-wave interactions: Application in an operational wave model. Ocean Modelling Vol. 70, 38-51.

Summary

1. Implemented TSA in WW3 and WWM
2. Tests with different source terms: ST1 ~ ST4
3. Reliable results for ‘academic’ JONSWAP tests
4. “ " fetch- and duration-limited growth
5. Turning winds: ongoing test …
6. N Atlantic tests with hypothetical constant winds
7. Computational efficiency improved
8. Optimization of TSA code is ongoing.

Acknowledgements: Panel on Energy R & D, NOPP ONR.

Wave generation and growth…

a balance equation …

$$\frac{\partial E(f,\theta)}{\partial t} = -\vec{c}_g \cdot \vec{\nabla} E(f,\theta) + \sum_k S_k(k,\theta)$$

where

- $\vec{c}_g$ = group velocity
- S_{in} = wind input
- S_{ds} = wave dissipation
- S_{nl} = nonlinear transfer due to wave-wave interactions

$S_{nl} \Rightarrow$ full Boltzmann Integral - FBI

For internal transfer of wave action (or energy) in the spectrum at n_1 *(e.g. at* $\mathbf{k}_1$) *via* wave-wave interactions by $\mathbf{k}_2, \mathbf{k}_3, \mathbf{k}_4$) - Hasselmann (1962), Zakharov (1966)

$$\frac{\partial n_1}{\partial t} \equiv S_{nl} = \int\int T(\mathbf{k}_1, \mathbf{k}_3)\, d\mathbf{k}_3$$

where

$$T(\mathbf{k}_1, \mathbf{k}_3) = 2\oint [n_1 n_3(n_4 - n_2) + n_2 n_4(n_3 - n_1)] C(\mathbf{k}_1, \mathbf{k}_2, \mathbf{k}_3, \mathbf{k}_4)\theta(|\mathbf{k}_1 - \mathbf{k}_4| - |\mathbf{k}_1 - \mathbf{k}_3|)|\partial W/\partial n|^{-1}\, ds,$$

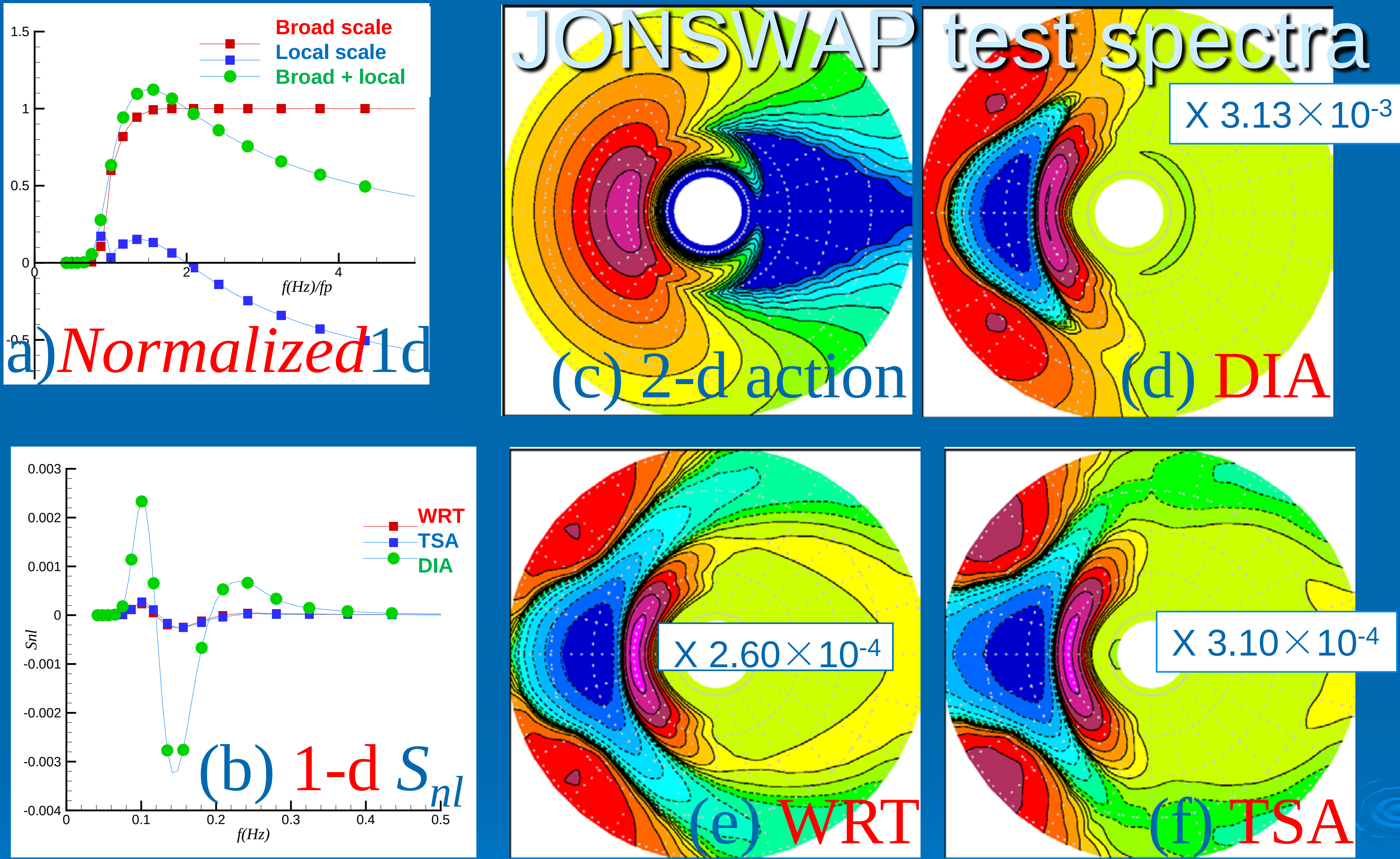
TSA – Two-Scale Approximation

$$n_i = n_{i\,[\text{broad-scale}]} + n_{i\,[\text{local-scale}]}\ ;\ i = 1,2,3,4$$

Neglect $n_{2\,[\text{local-scale}]}$ and $n_{4\,[\text{local-scale}]}$

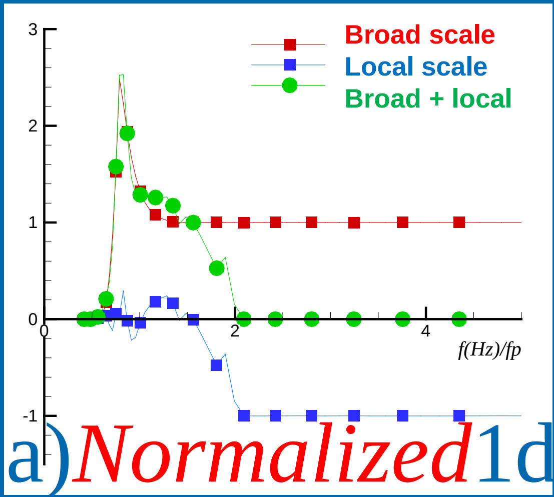
[Resio and Perrie 2008; Perrie & Resio 2009]

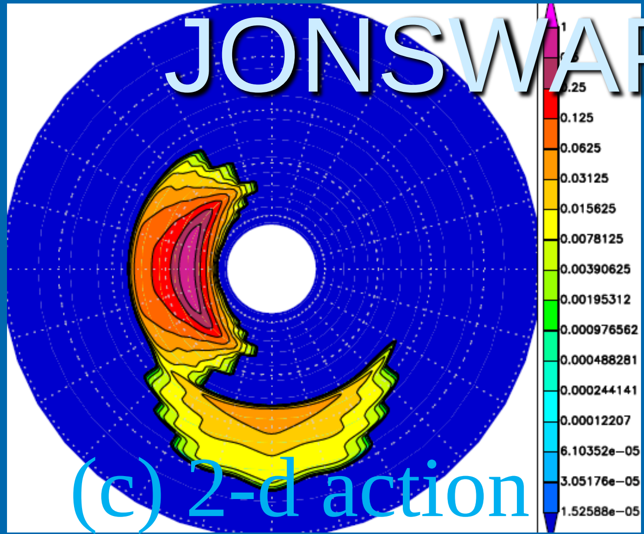
JONSWAP test spectra

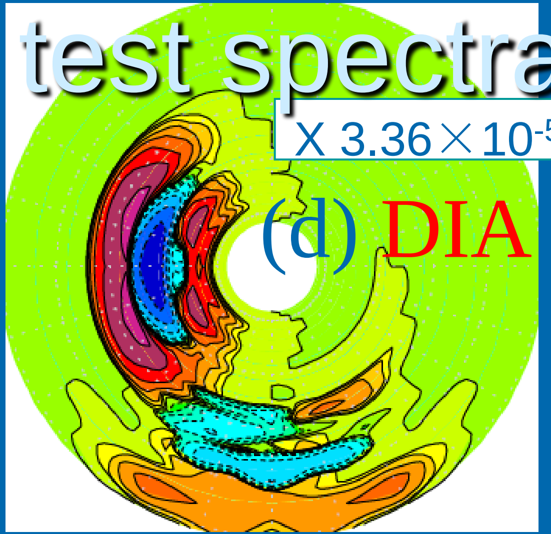


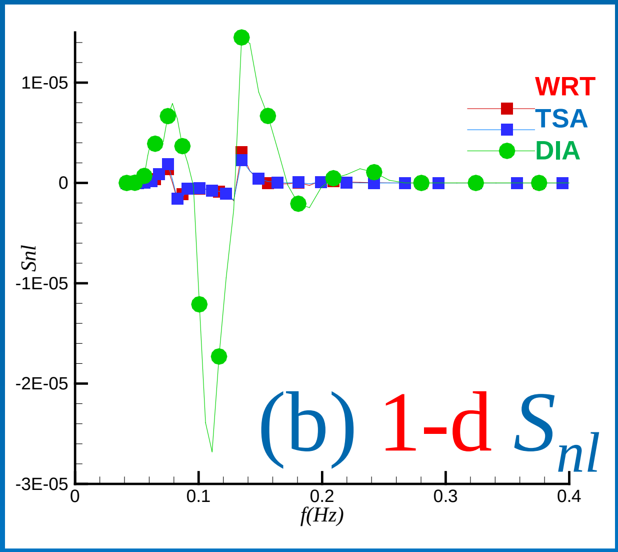
JONSWAP γ=1 with Hasselmann-Mitsuyasu directional:
(a)broad- and local-scale terms normalized by f^{-4},
(b)1-d comparison of DIA, WRT and TSA, (c) 2-d action density n_i,
(d) $S_{nl}(f,\theta)$ results from DIA (e) WRT, (f) TSA. f_p=0.1, α=0.0081, σ_A=0.07, σ_B=0.09.

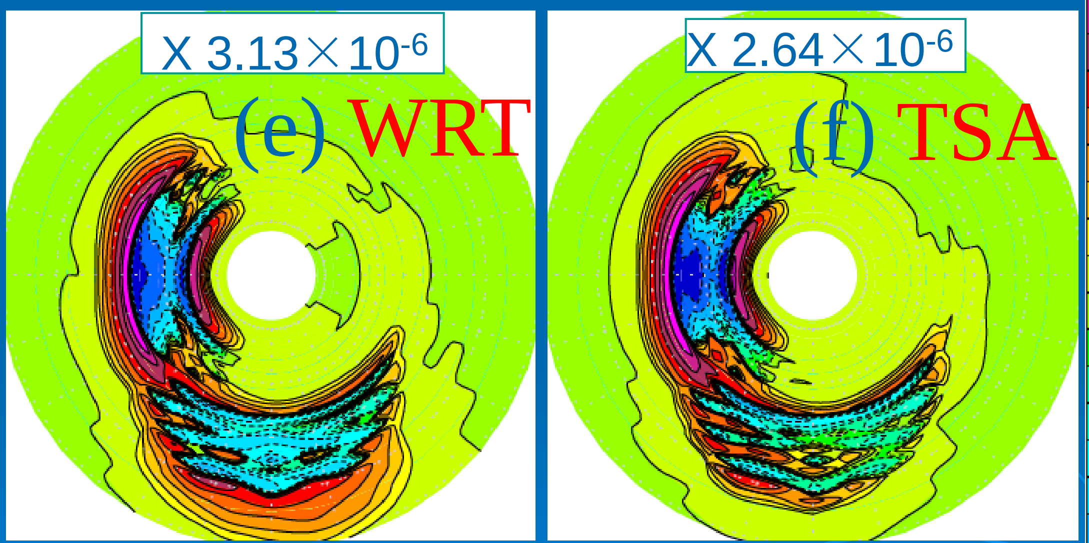
JONSWAP test spectra

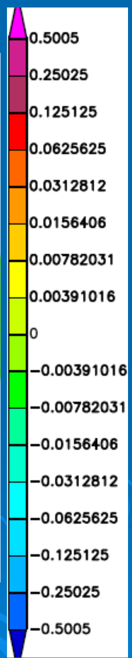








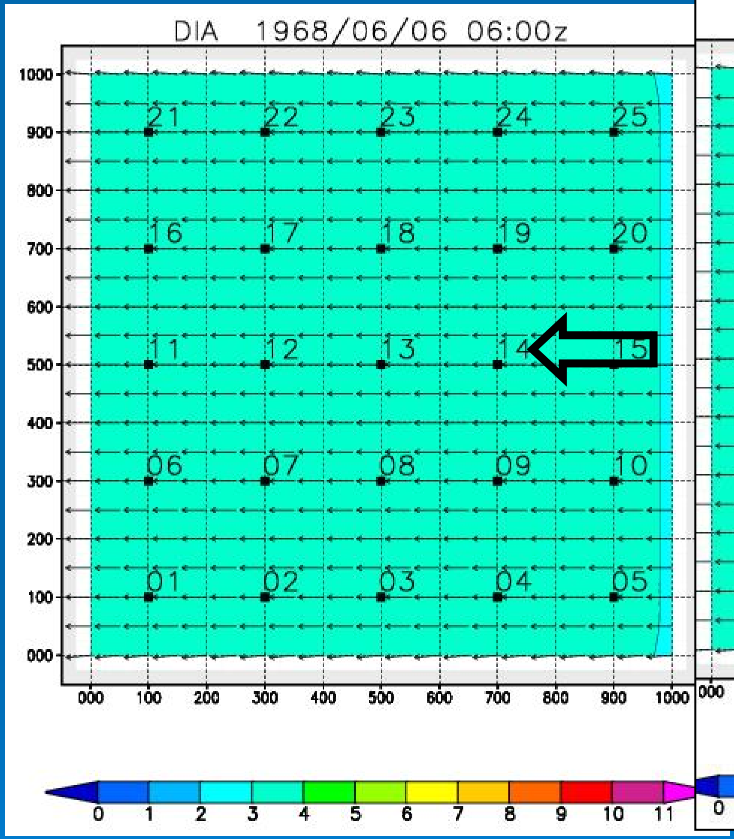


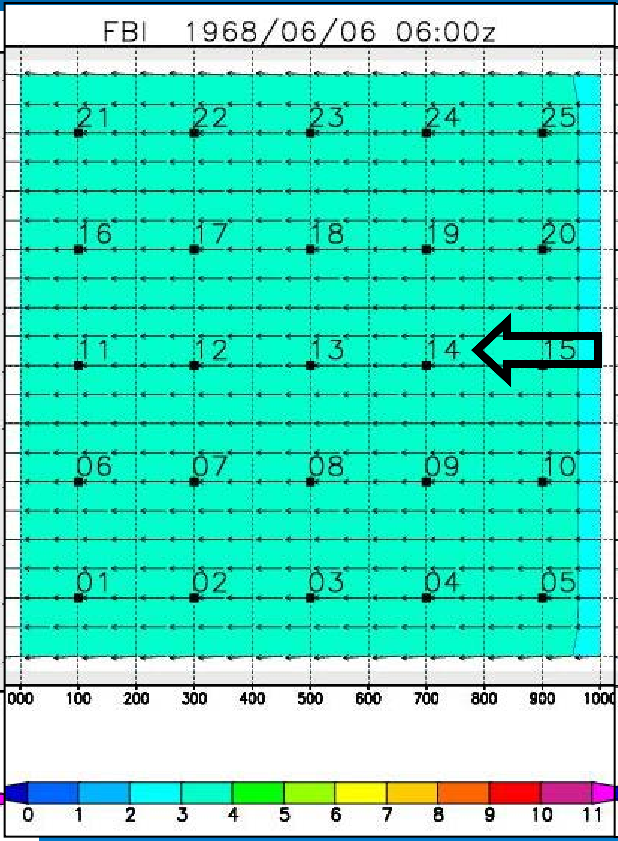


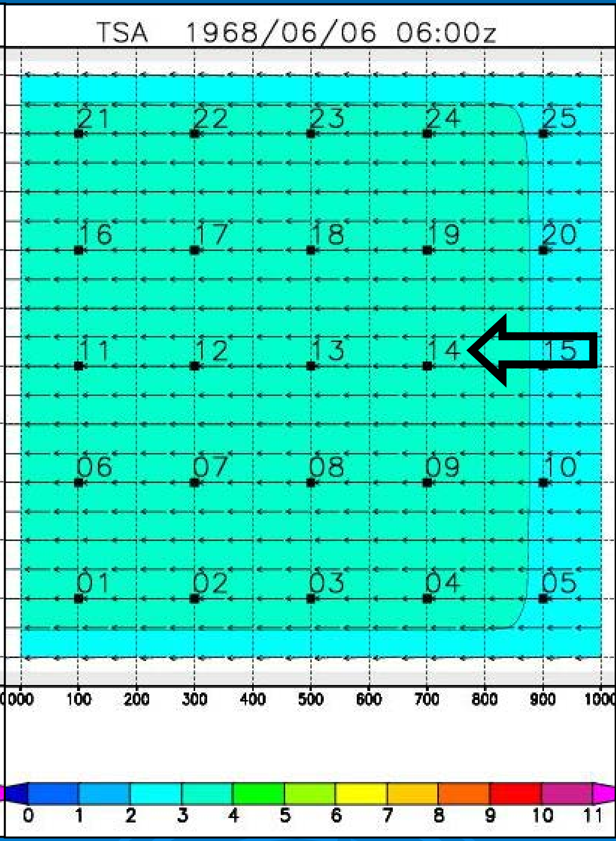
JONSWAP **sheared** spectrum with Hasselmann-Mitsuyasu directional:
(a)broad- and local-scale terms normalized by f^{-4},
(b)1-d comparison of DIA, WRT and TSA, (c) 2-d action density n_i,
(d) $S_{nl}(f,\theta)$ results from DIA (e) WRT (f) TSA. f_p=0.1, α=0.0081, σ_A=0.07, σ_B=0.09.

WW3 – with 'old' ST1: fetch-limited growth

6 hr







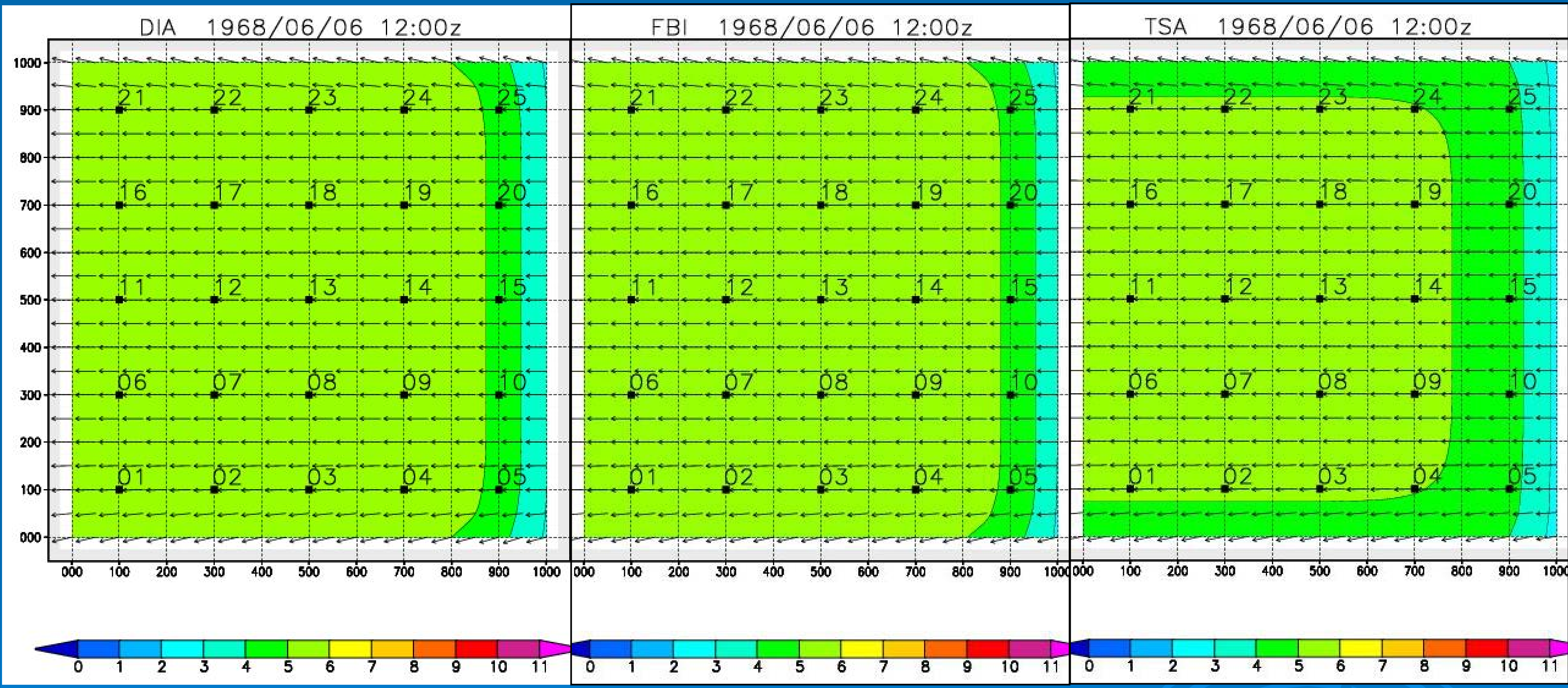
DIA

FBI

TSA

WW3 – with ‘old’ ST1: fetch-limited growth

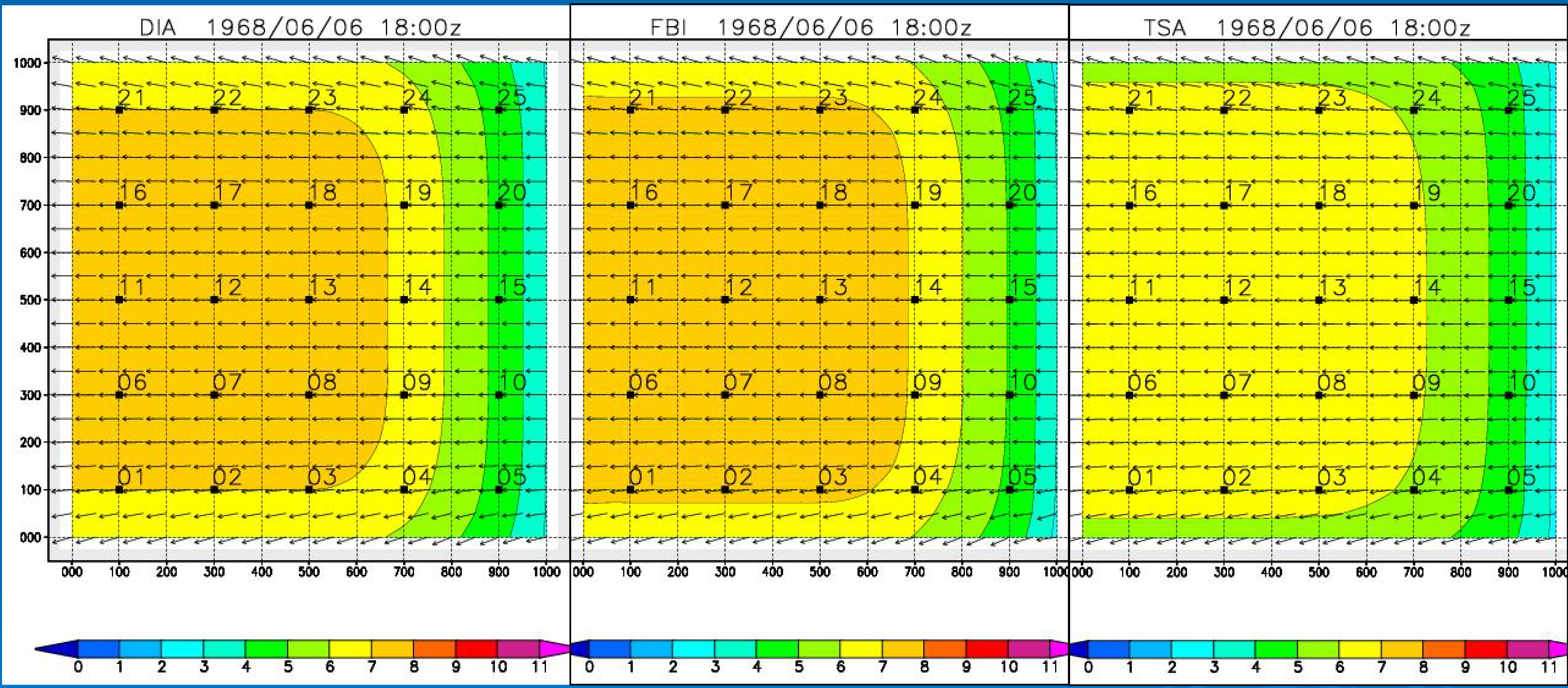
12 hr



DIA FBI TSA

WW3 – with ‘old’ ST1: fetch-limited growth

18 hr



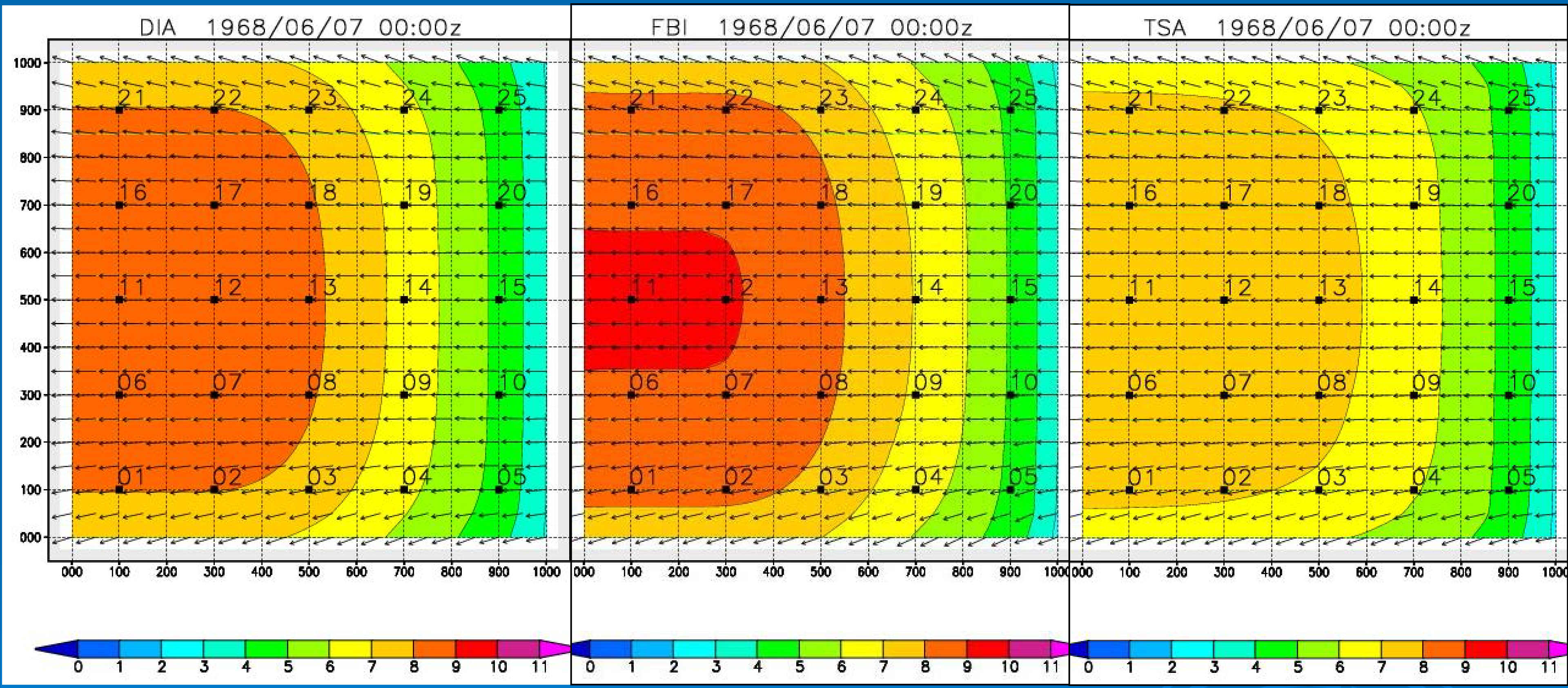
DIA

FBI

TSA

WW3 – with 'old' ST1: fetch-limited growth

24 hr



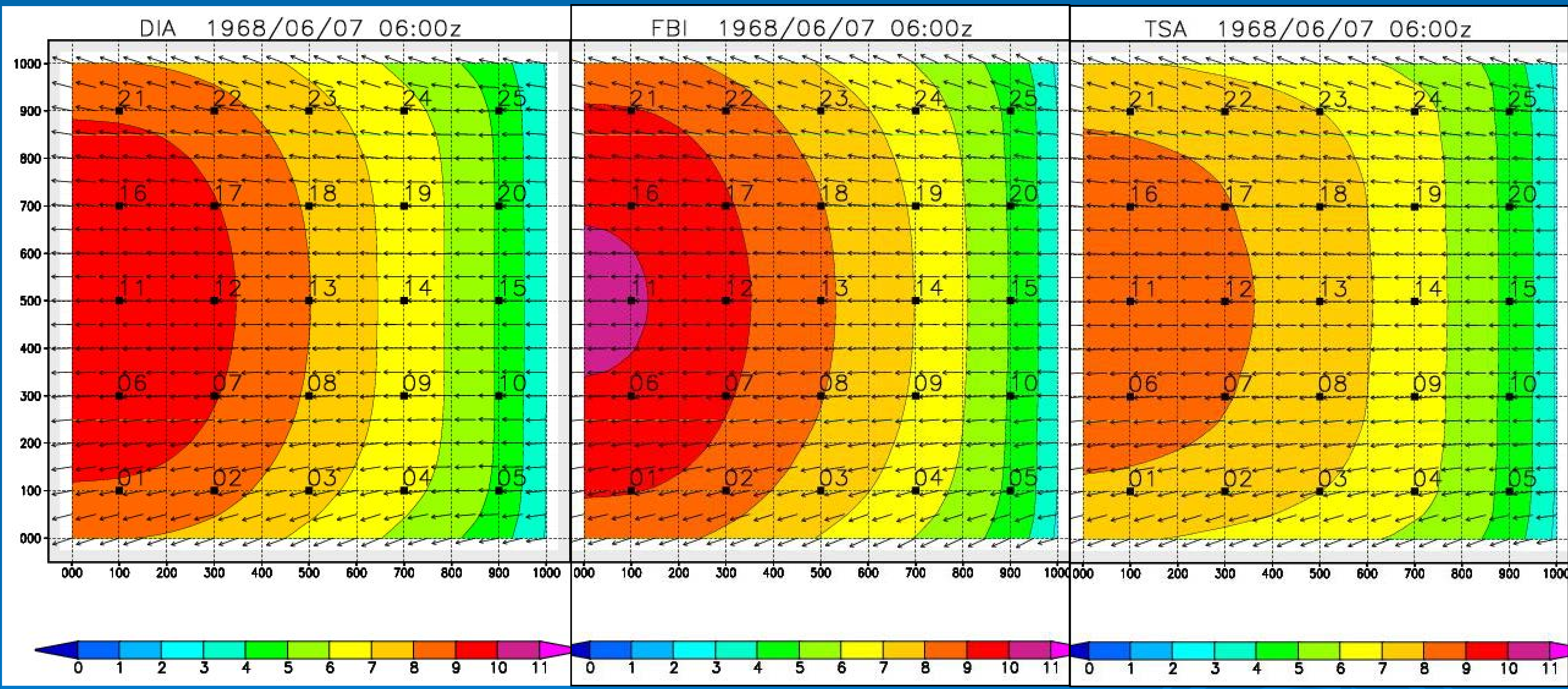
DIA

FBI

TSA

WW3 – with 'old' ST1: fetch-limited growth

30 hr



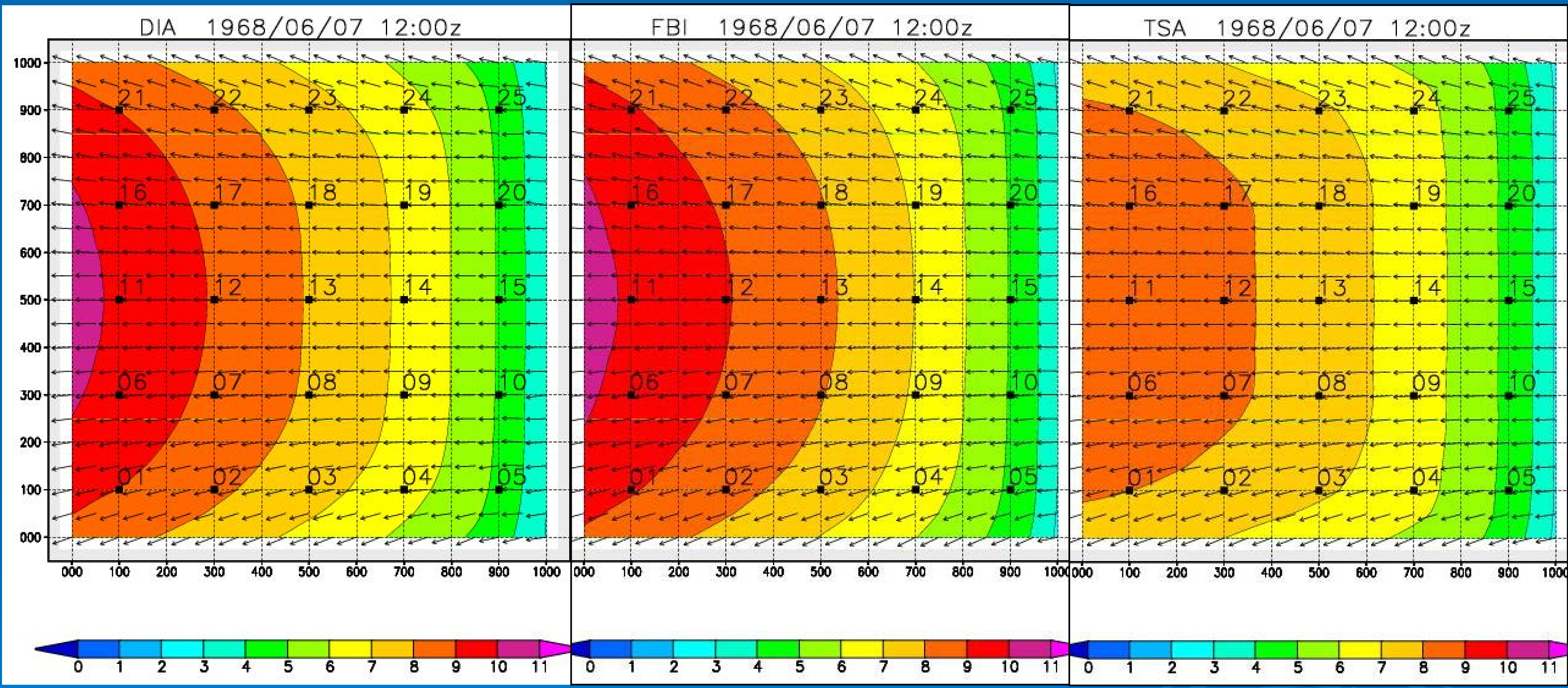
DIA

FBI

TSA

WW3 – with 'old' ST1: fetch-limited growth

36 hr



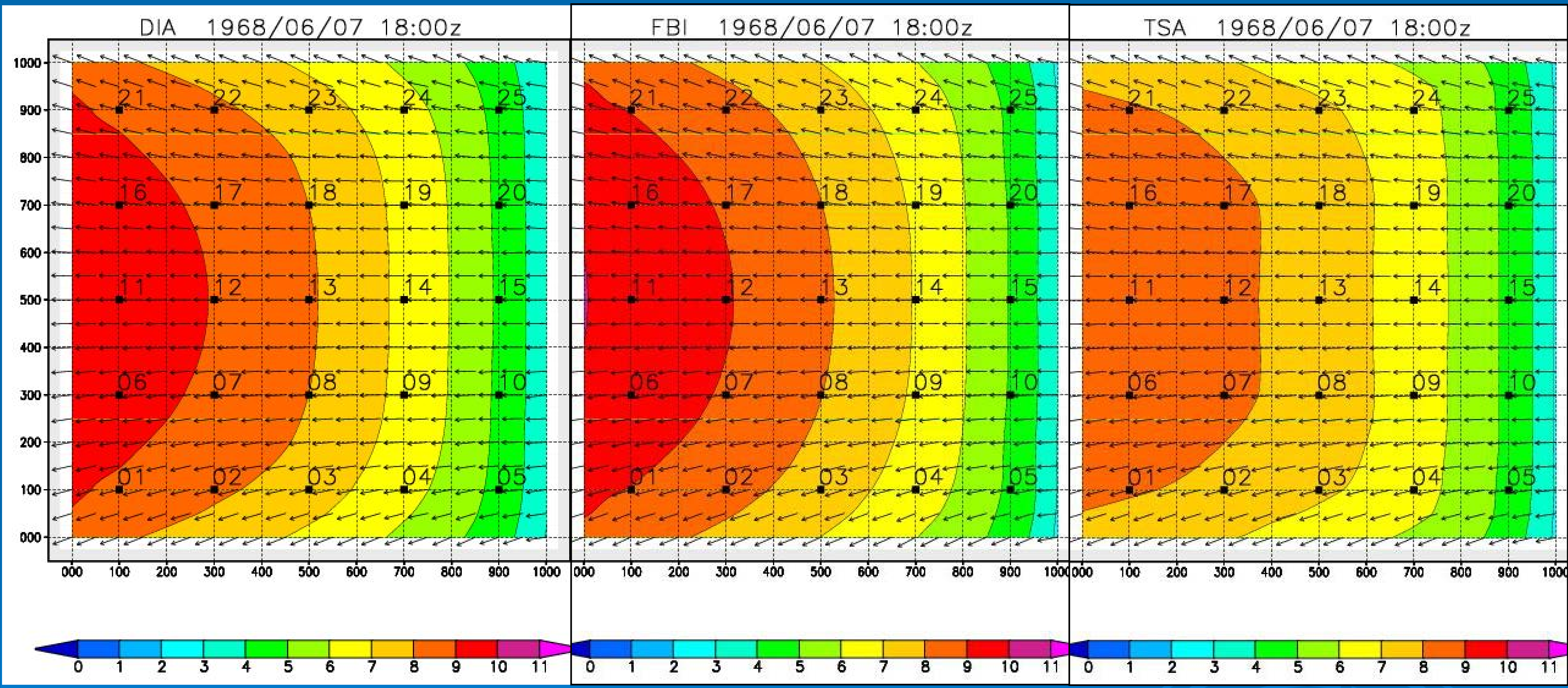
DIA

FBI

TSA

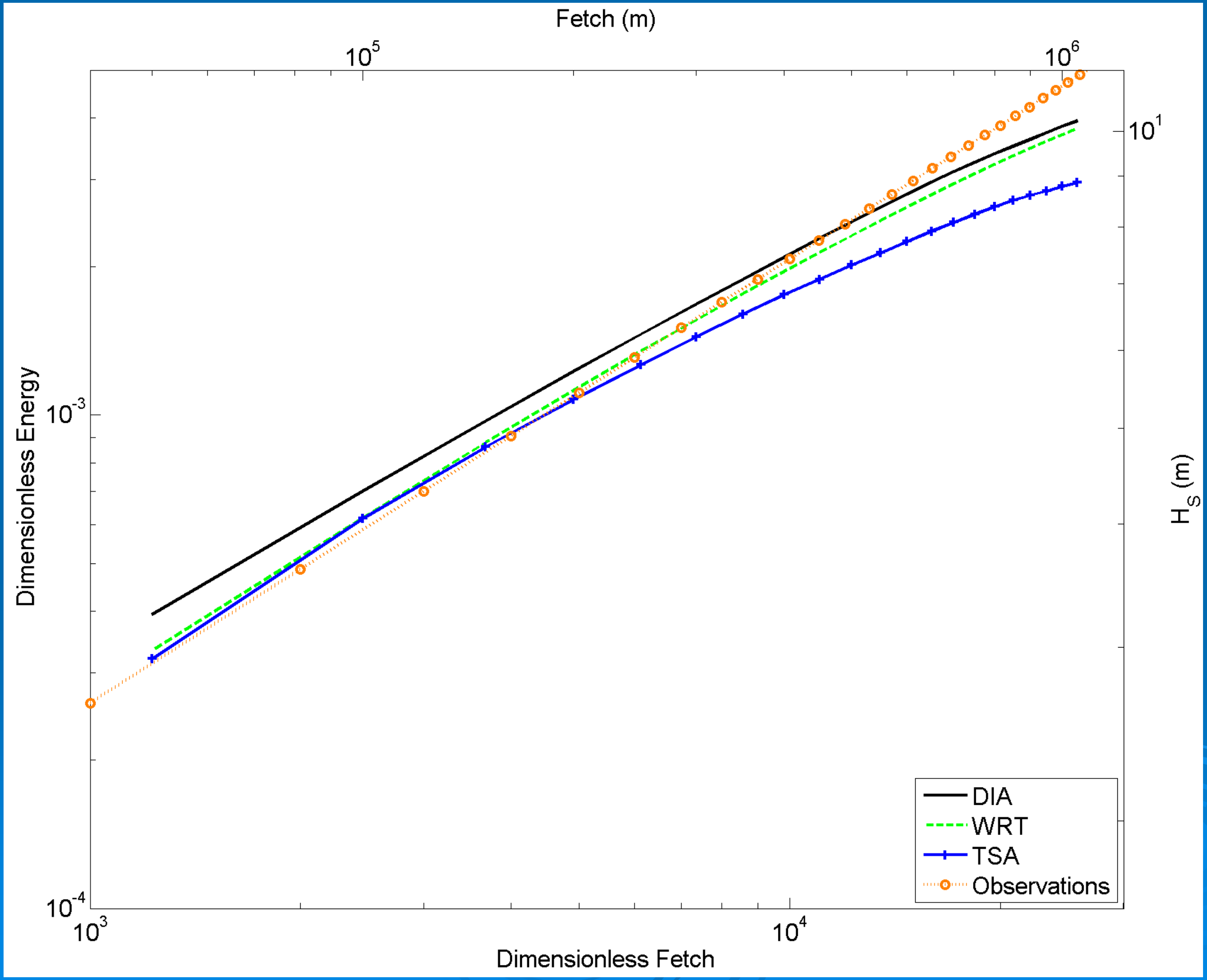
WW3 – with 'old' ST1: fetch-limited growth

42 hr

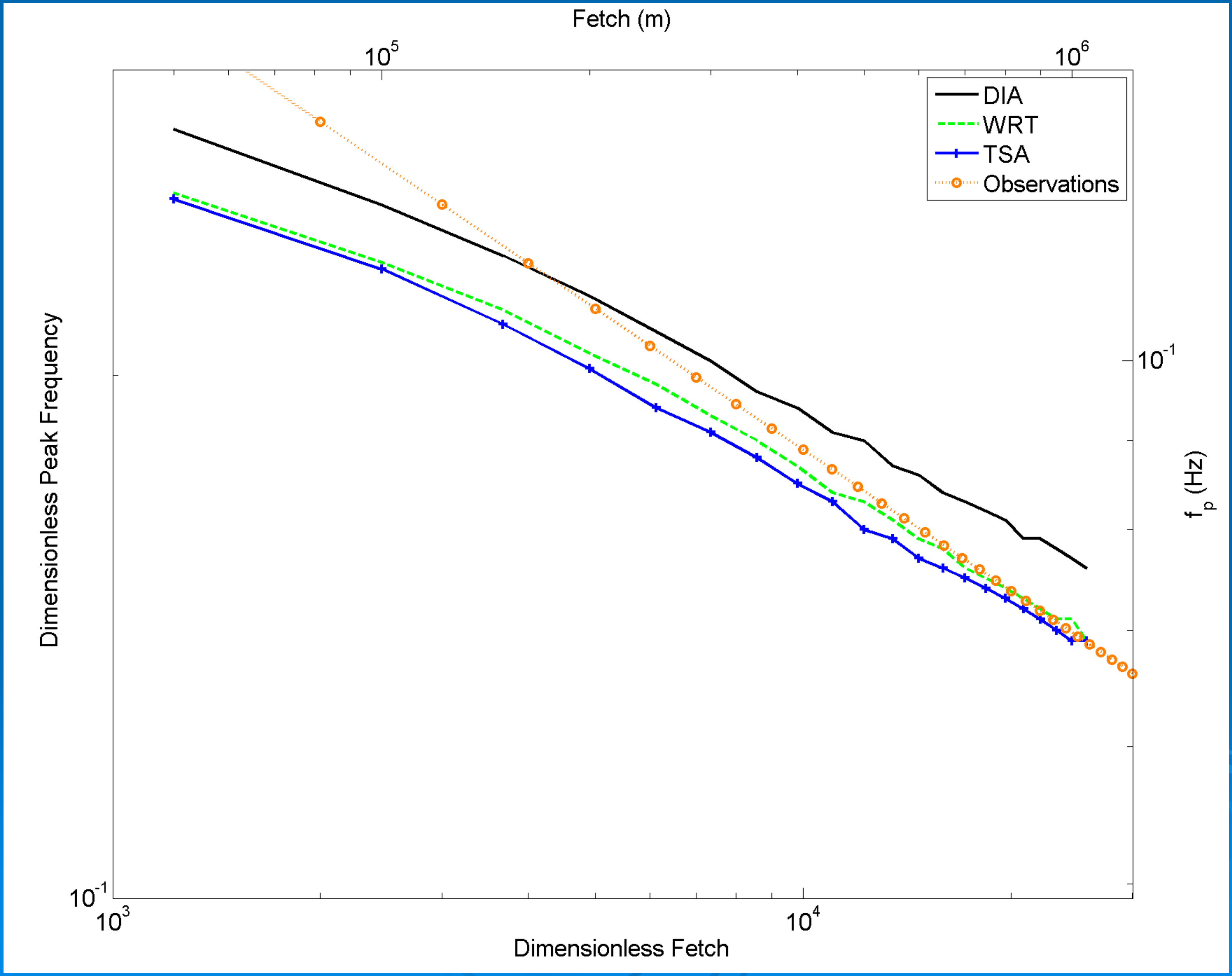


DIA FBI TSA

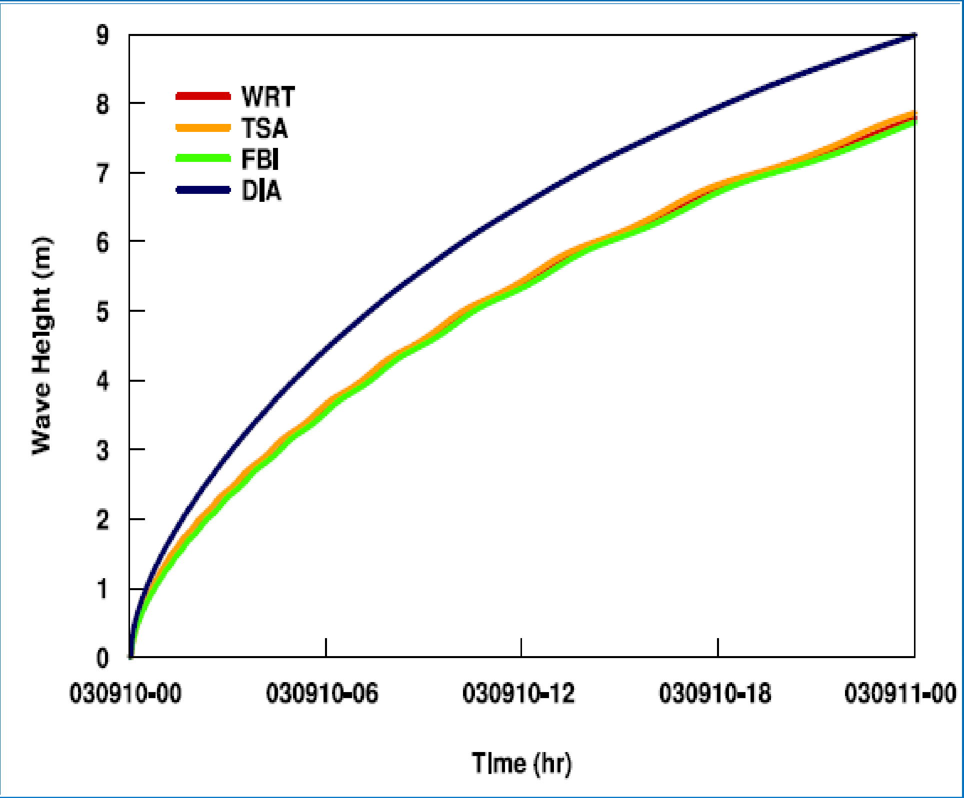
WW3 – with 'old' ST1: fetch-limited growth

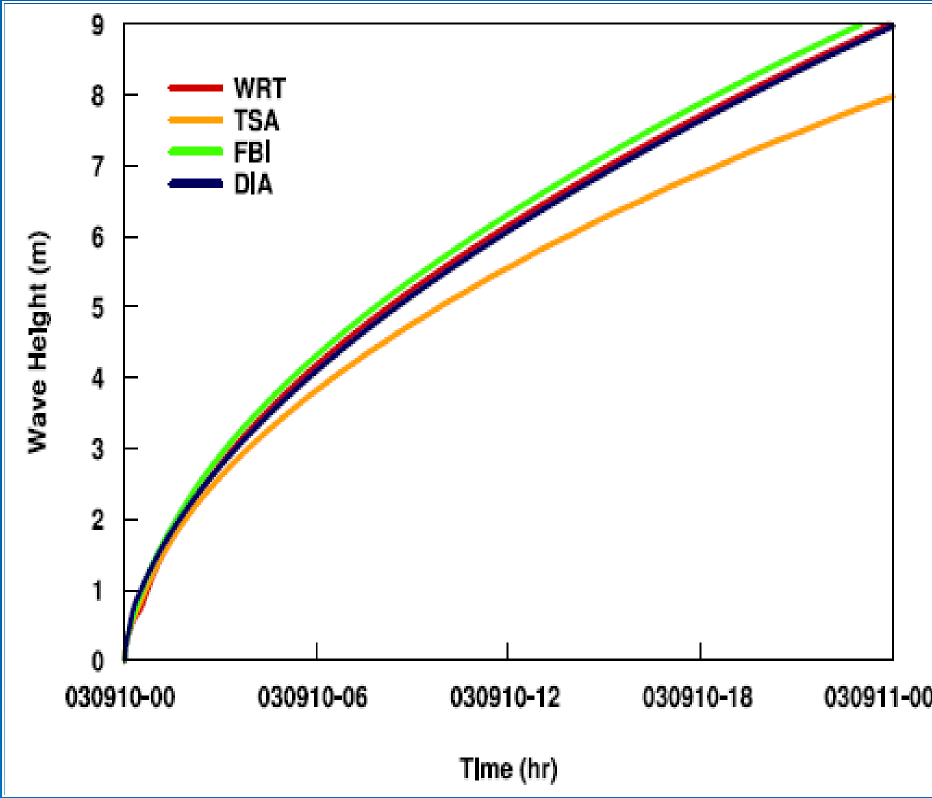


WW3 – with ‘old’ ST1: fetch-limited growth



1-point time integration

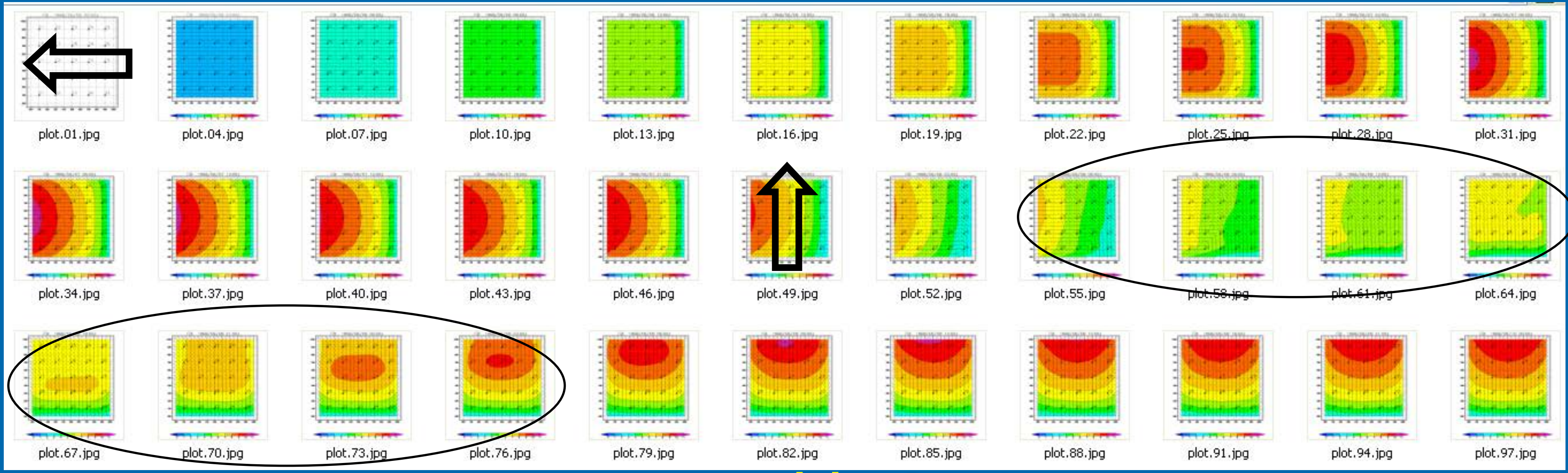




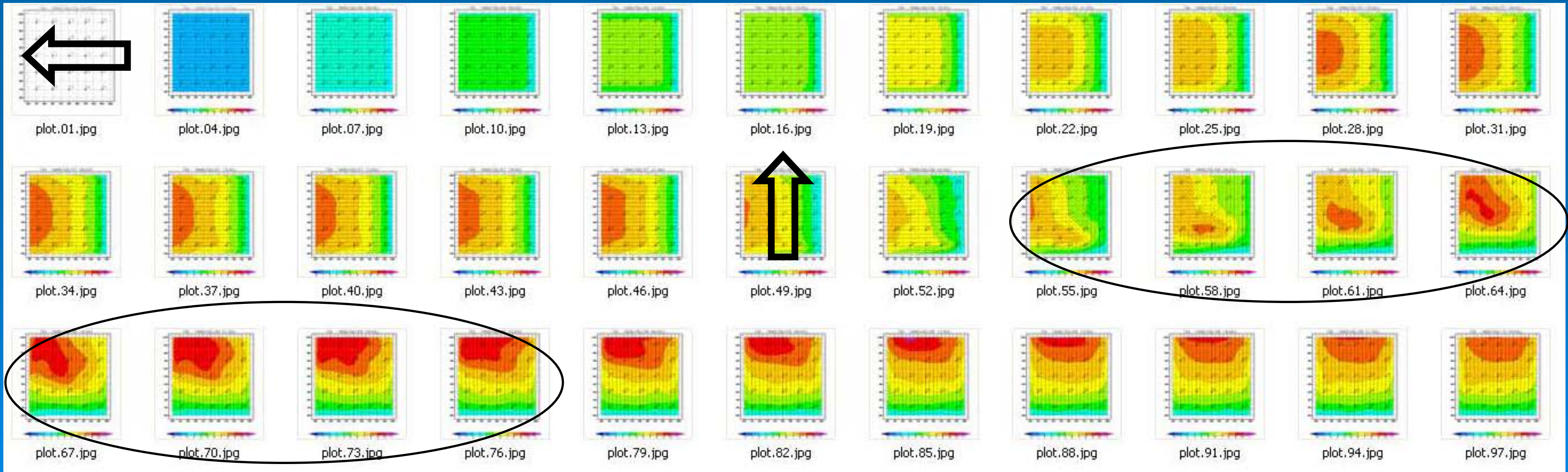
WWM (Roland et al., 2012) with **ST4**
From Ardhuin et al. (2010)

WW3 (Tolman, 2009) with **ST2**
From Tolman + Chalikov (1996)

Ongoing issue: turning winds by 90º at 48 hr

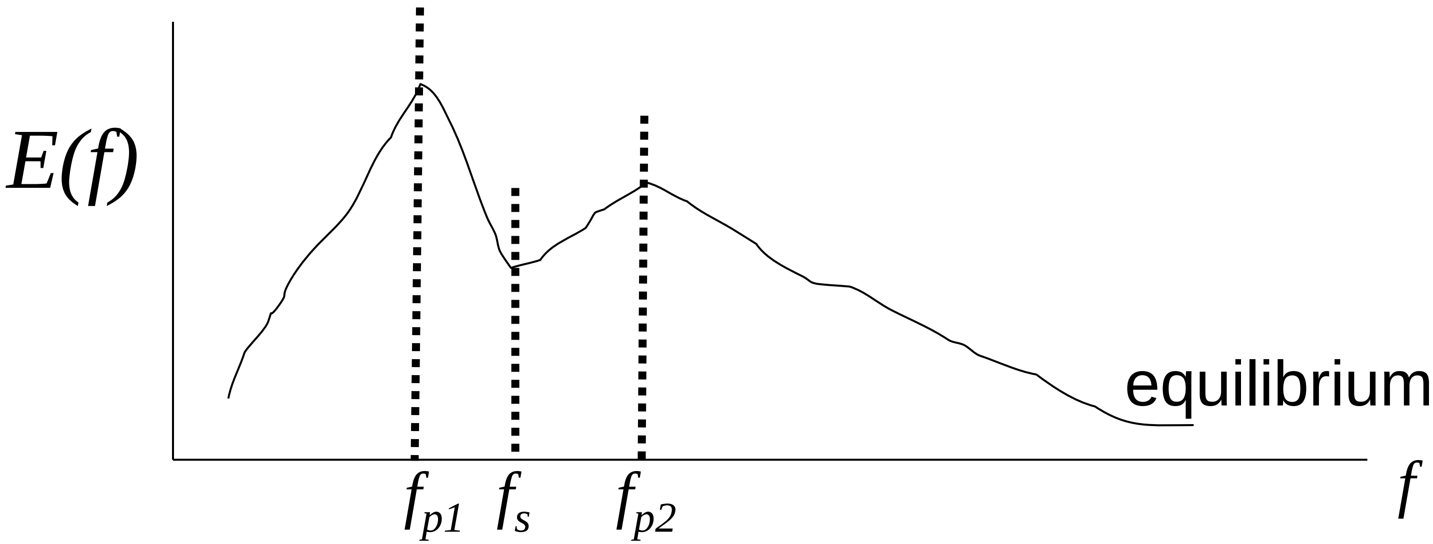


WRT with ST1



original TSA with ST1

Multiple spectral peaks - mTSA



Broad-scale term parameterization…?

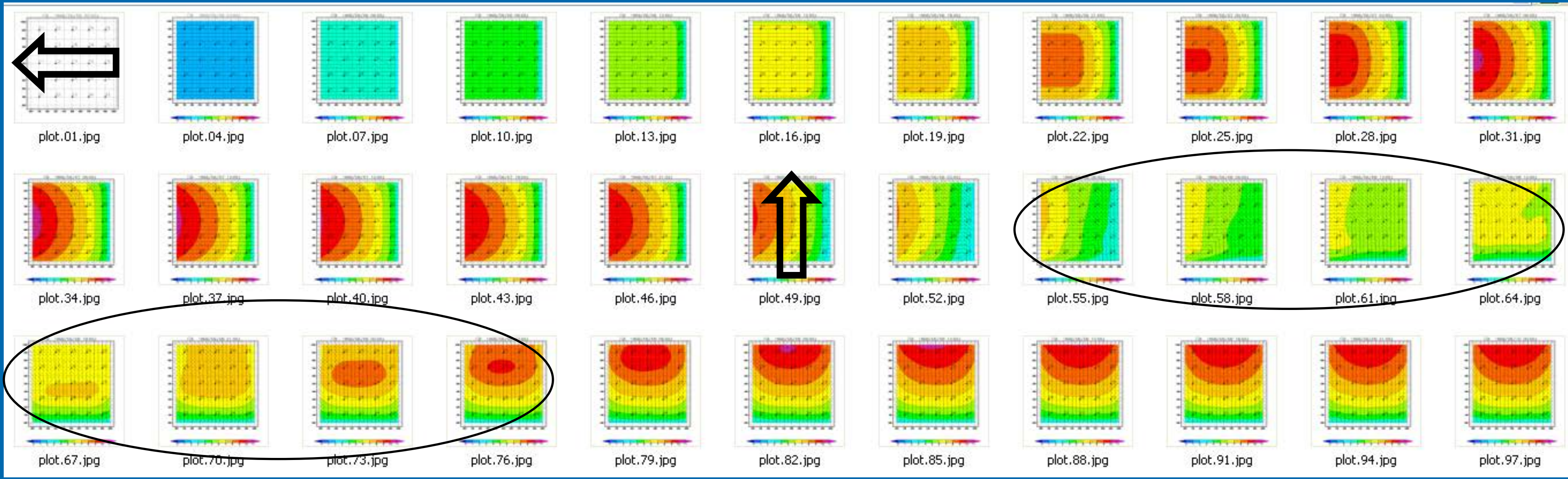
$F(k)_{Norm} = F(k) \times k^{2.5} / \beta$ [Resio&Perrie, 1989; Resio et al. 2004…]

Should be $\beta \sim 1/\Delta f \sum[F(k) \times k^{2.5}]|_{\text{equilibrium range}}$

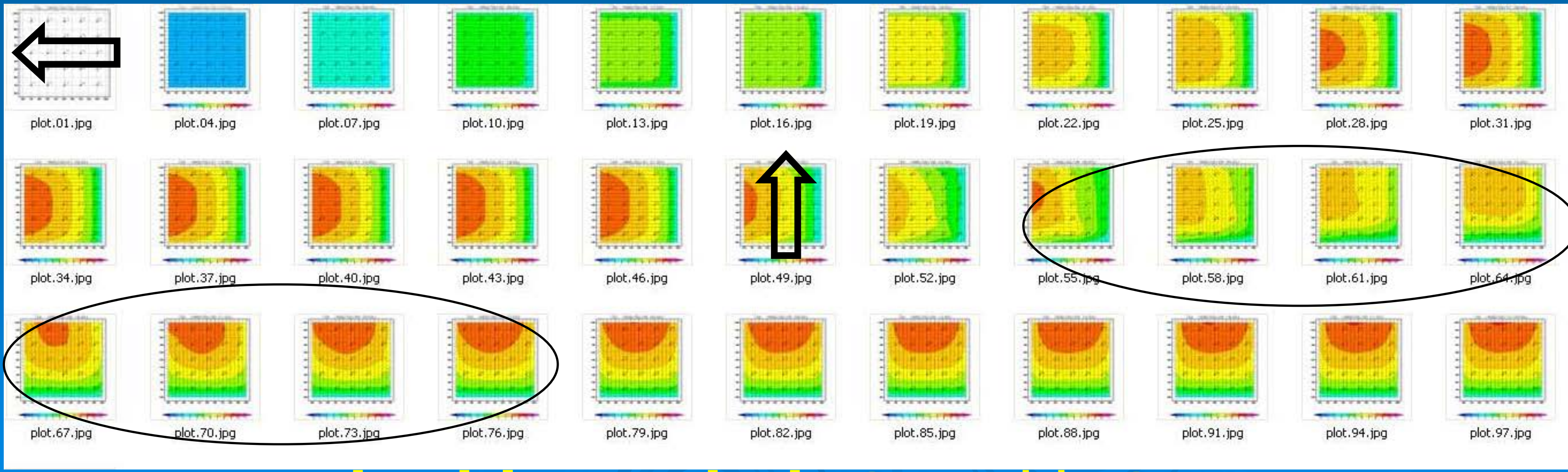
But equilibrium range is hard to define when f_{p1} and f_{p2} are close…

So *let* $\beta = F(k) \times k2.5\ |f_s$ … *for the first peak …*

Ongoing issue: turning winds by 90º at 48 hr



WRT with **ST1**



New double-peak dTSA with **ST1**

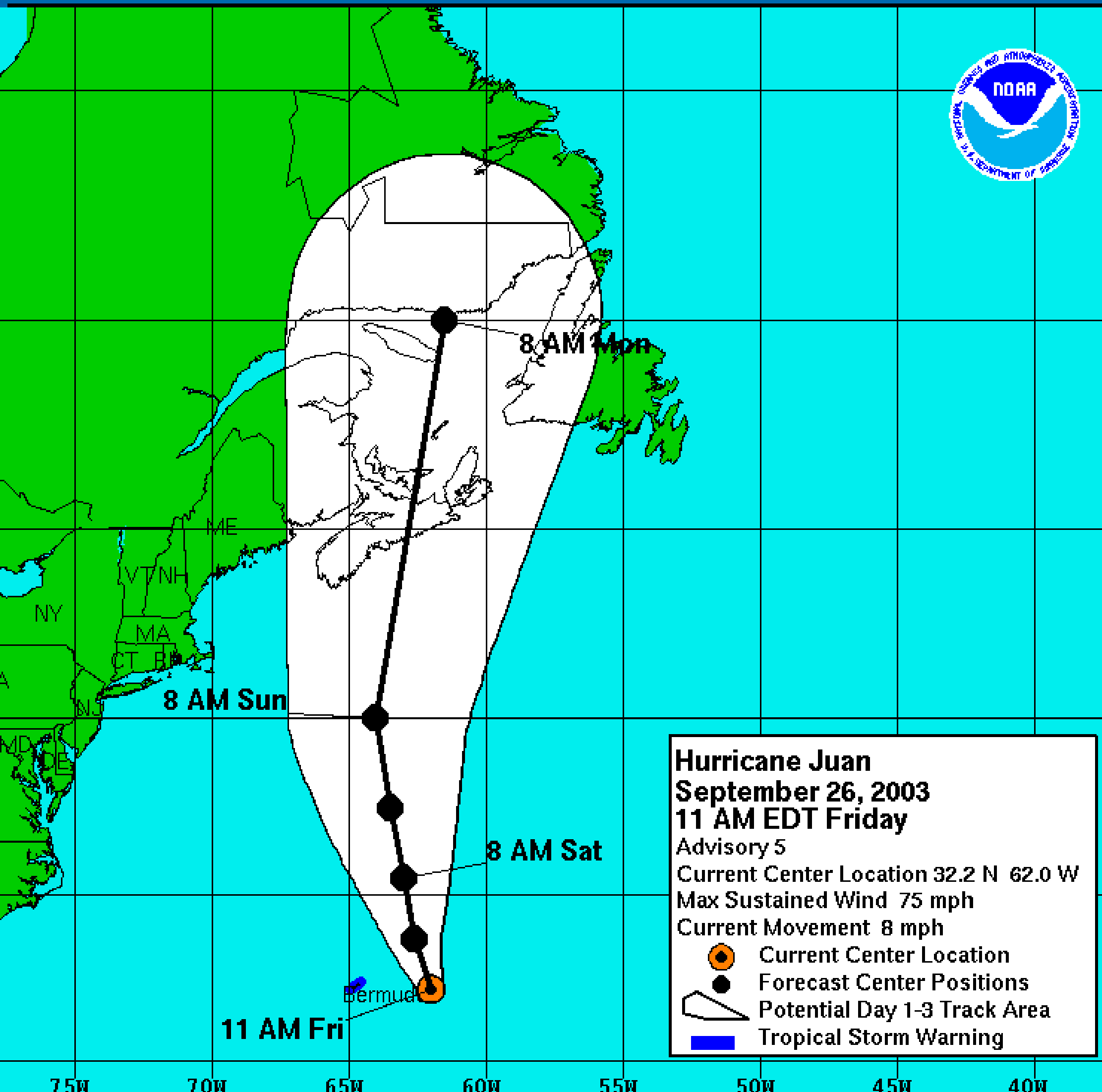
Hurricane Juan (2003)

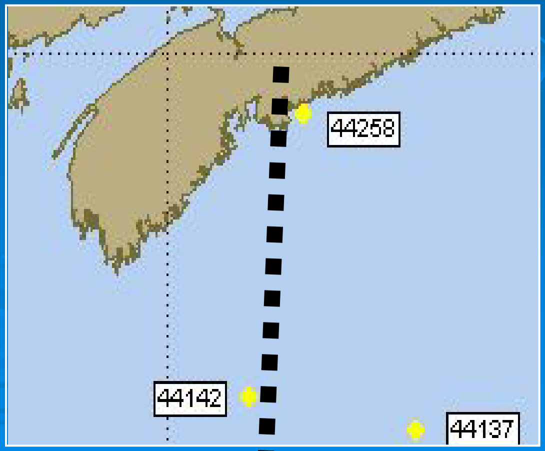
ack at max. wind radius

: 2-3 AM UTC 29 Sept.

MSL

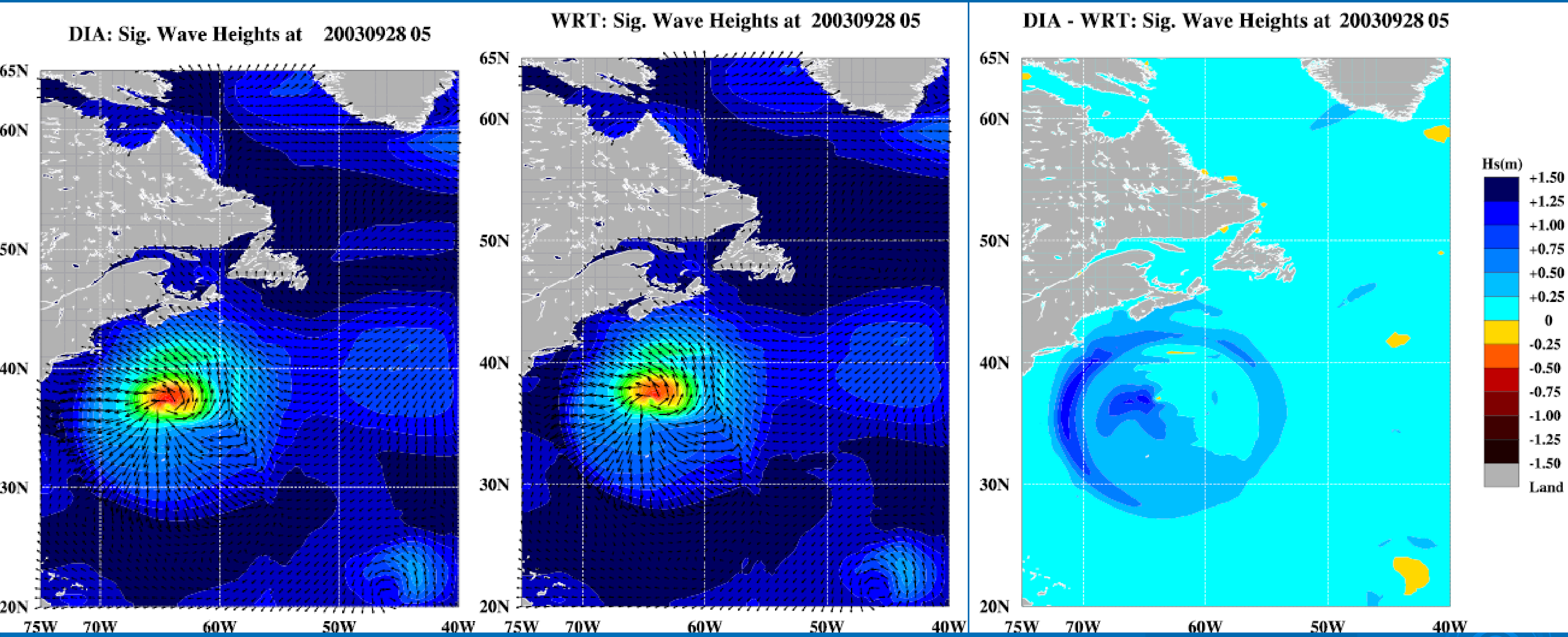
k

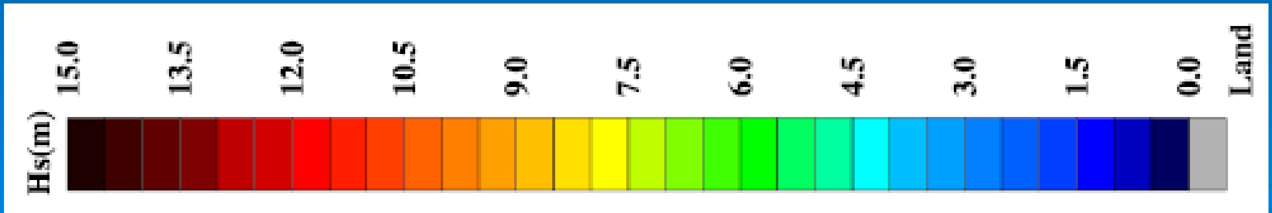




Hurricane Juan wave heights, Hs

DIA | FBI | *difference* DIA-FBI

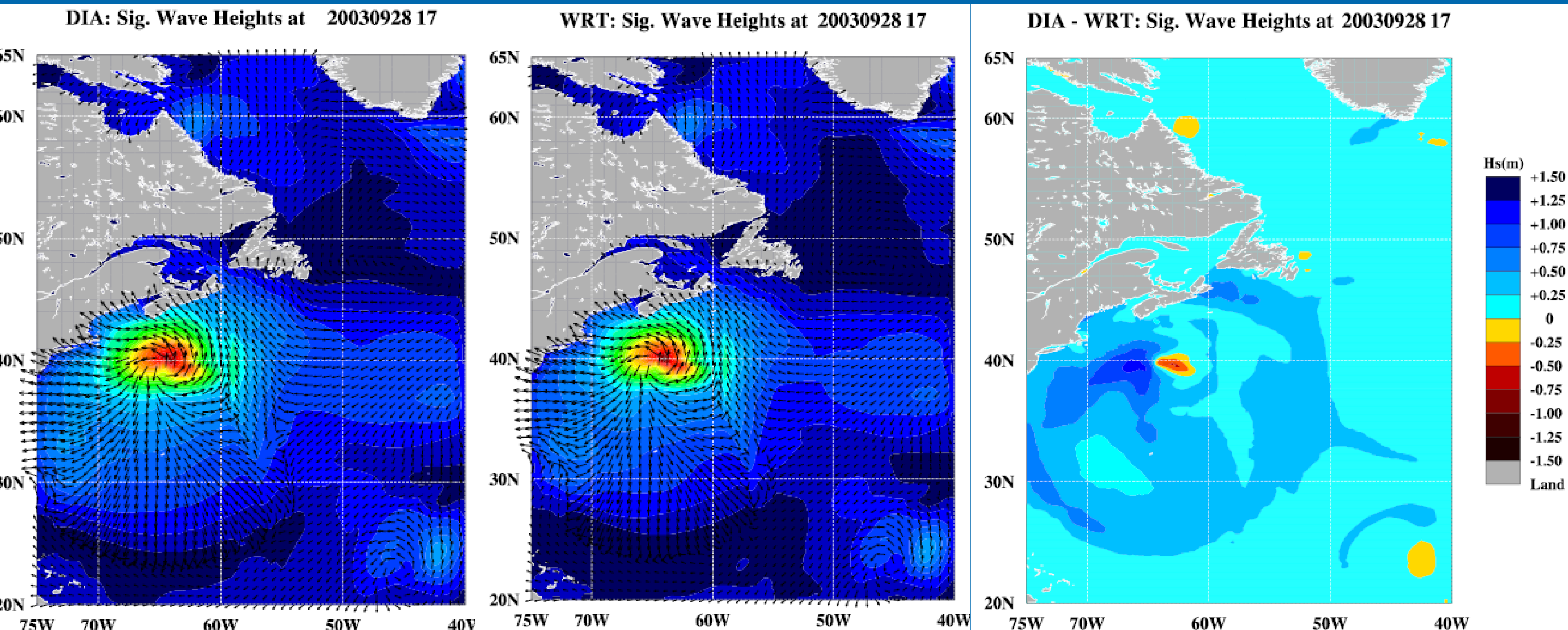


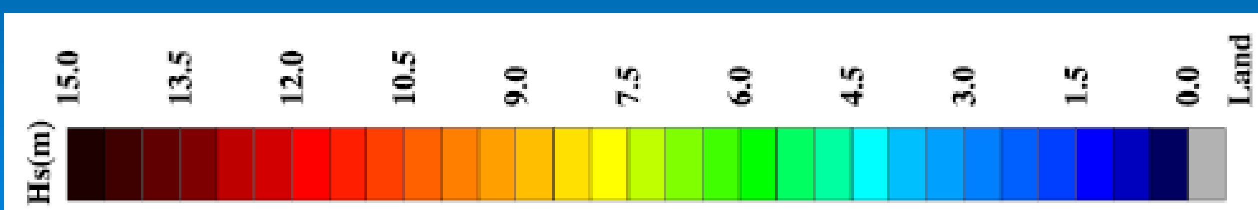


~10%

Hurricane Juan wave heights, Hs

DIA | FBI | *difference* DIA-FBI

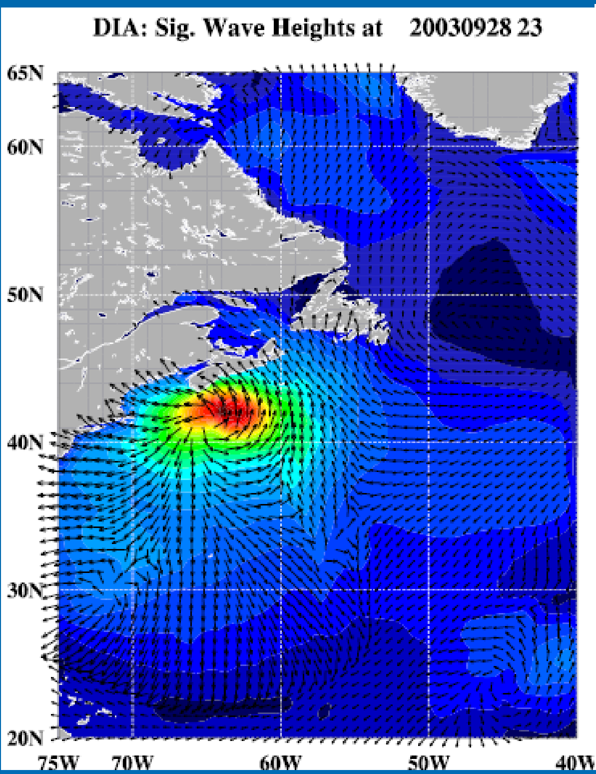




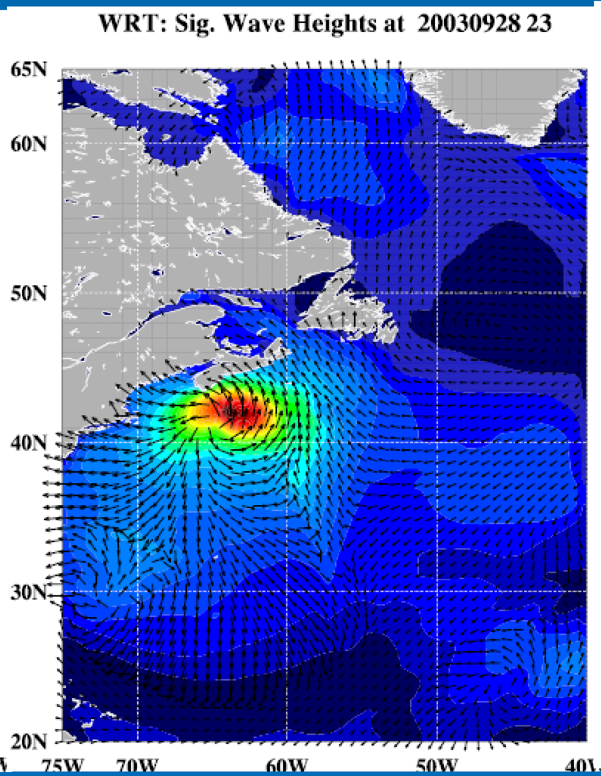
~15%

Hurricane Juan wave heights, Hs

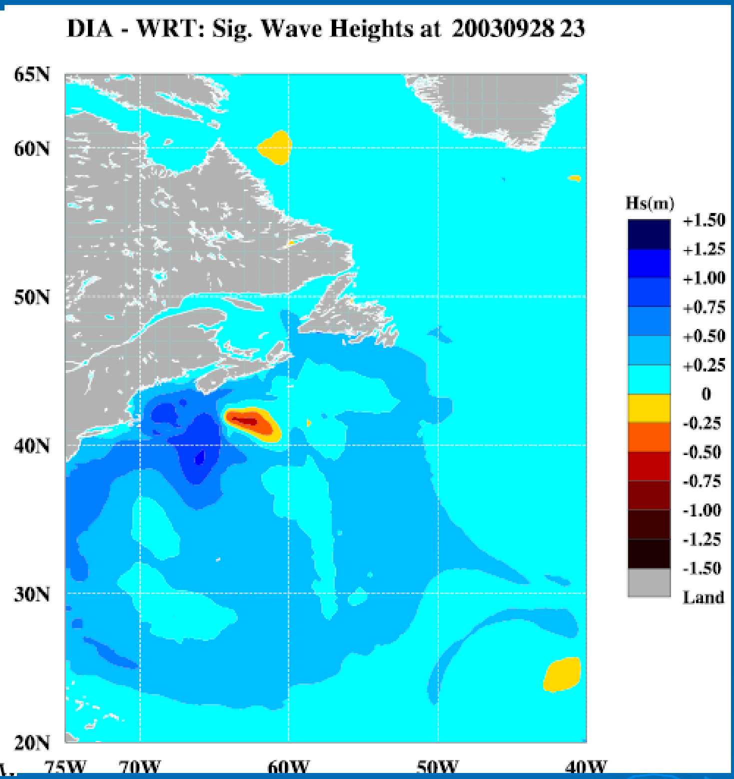
DIA

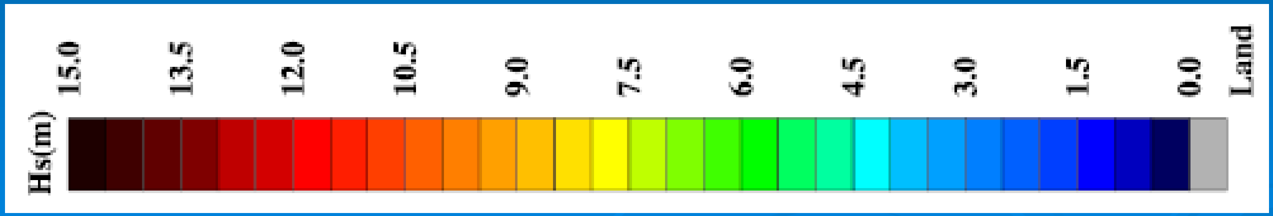


FBI



difference DIA-FBI





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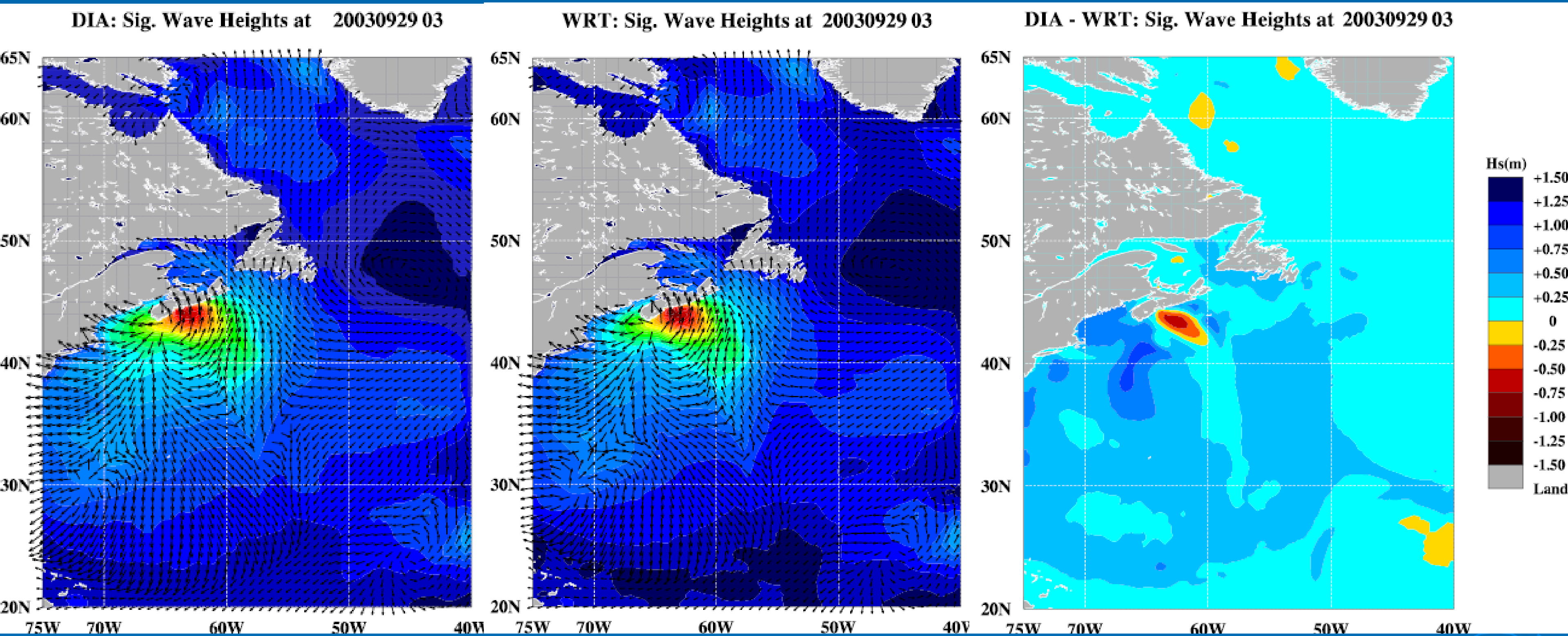
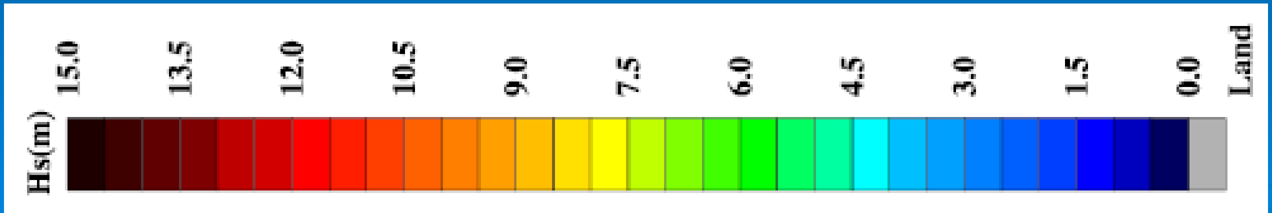
Hurricane Juan wave heights, Hs

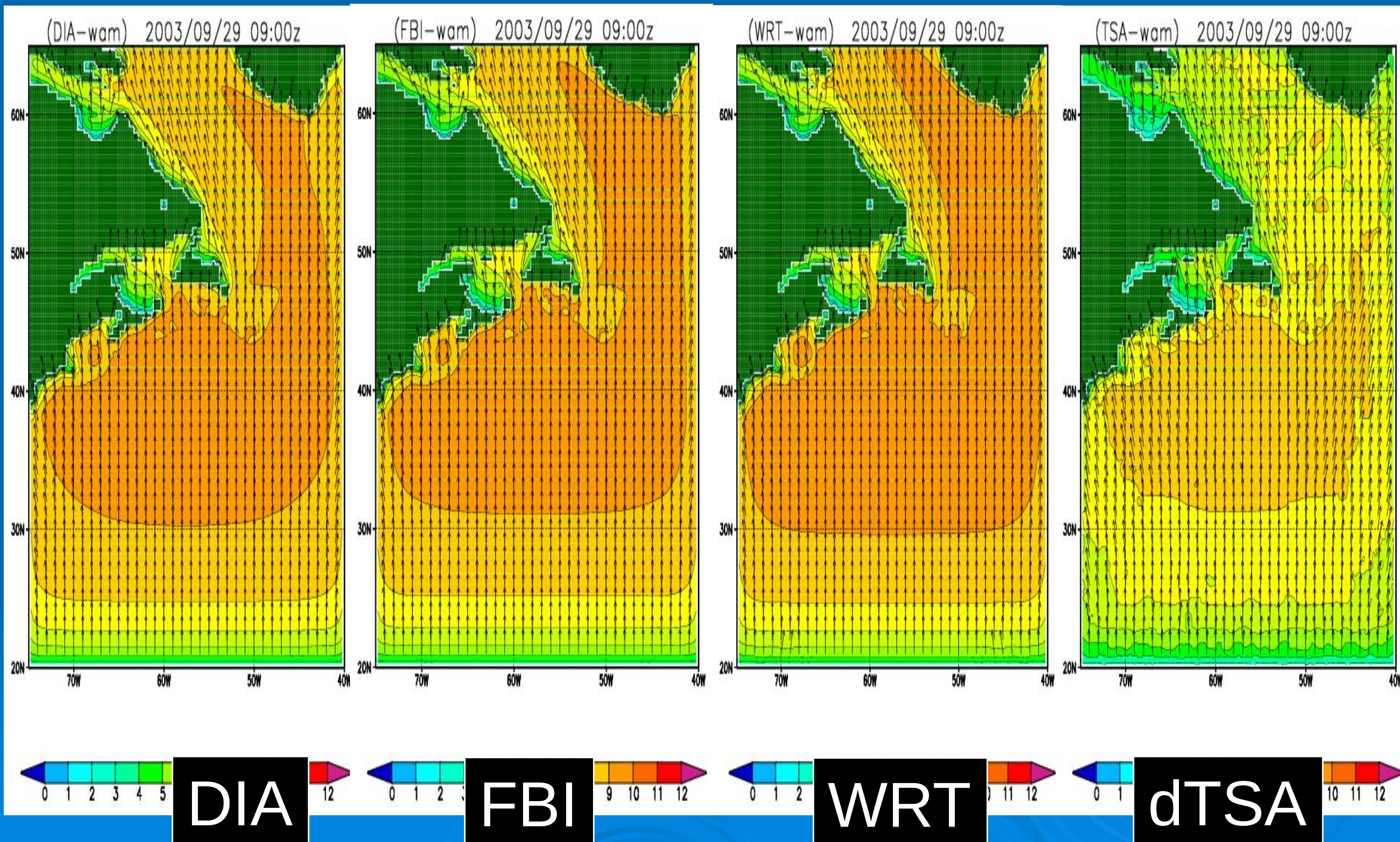
DIA | FBI | *difference* DIA-FBI





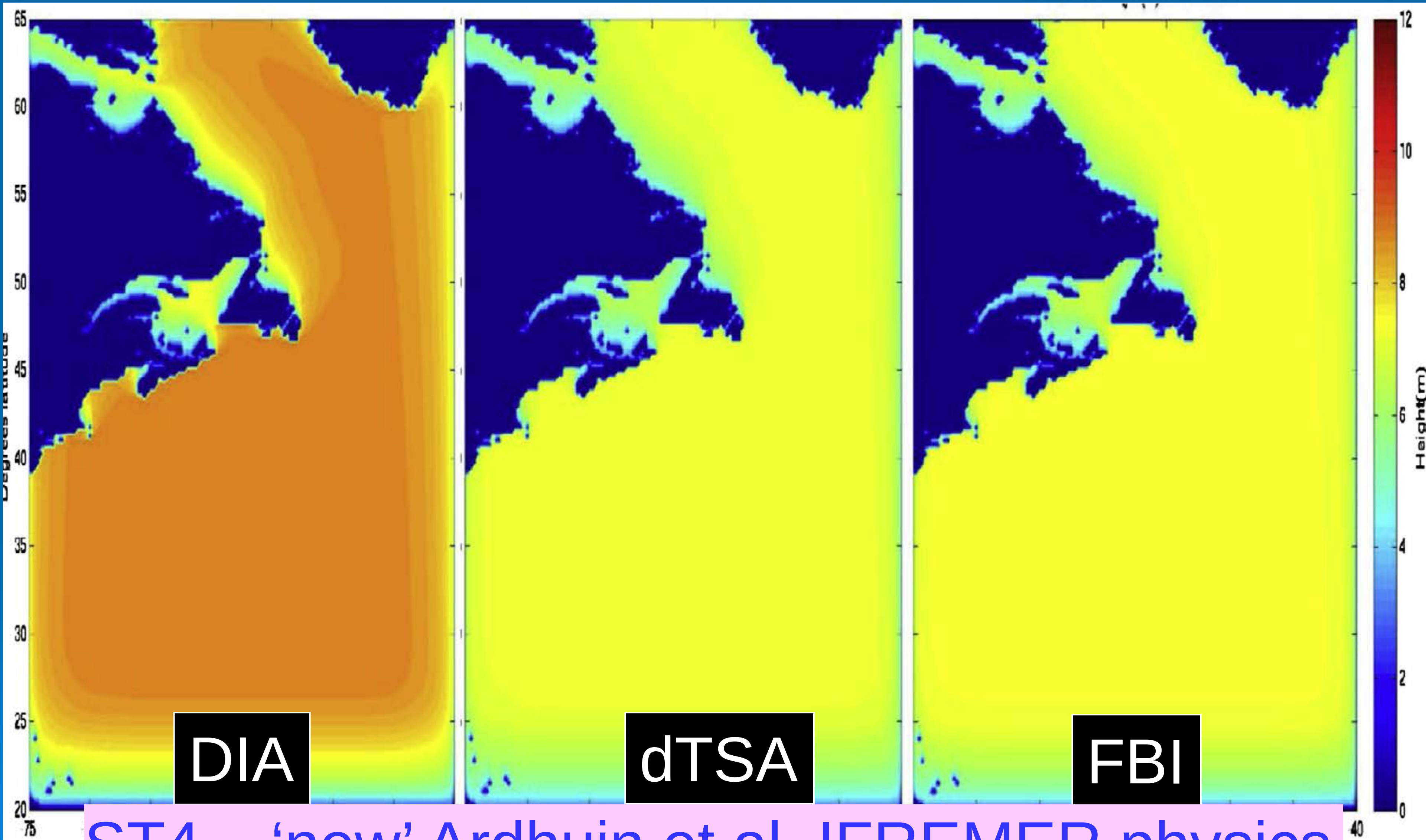
~15%

WW3 – constant U10 – 55 hr ‘old’ **ST1**



ST1 – wamCy3 physics

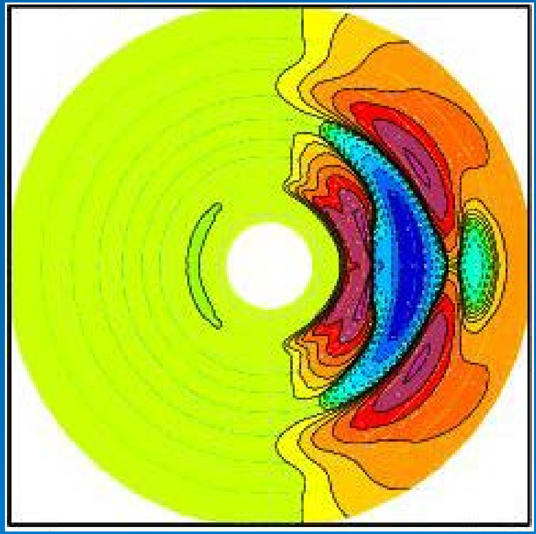
WW3 – constant U10 – 55 hr ‘new’ **ST4**



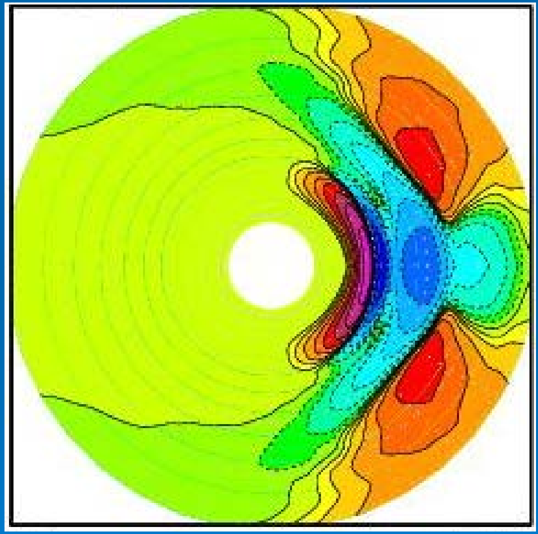
ST4 – ‘new’ Ardhuin et al. IFREMER physics

Computational time

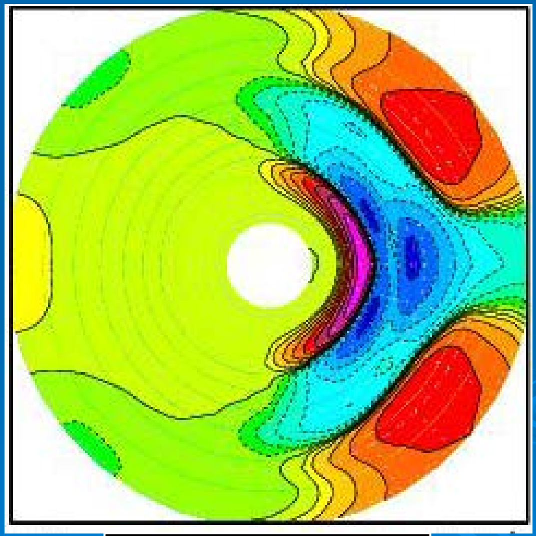
- Alternate frequency, angles & interaction points can speed up TSA about 30-40 × or more
- Presently, best accurate results are 20 × DIA
- Optimization of TSA code is ongoing



DIA



WRT



dTSA,a

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