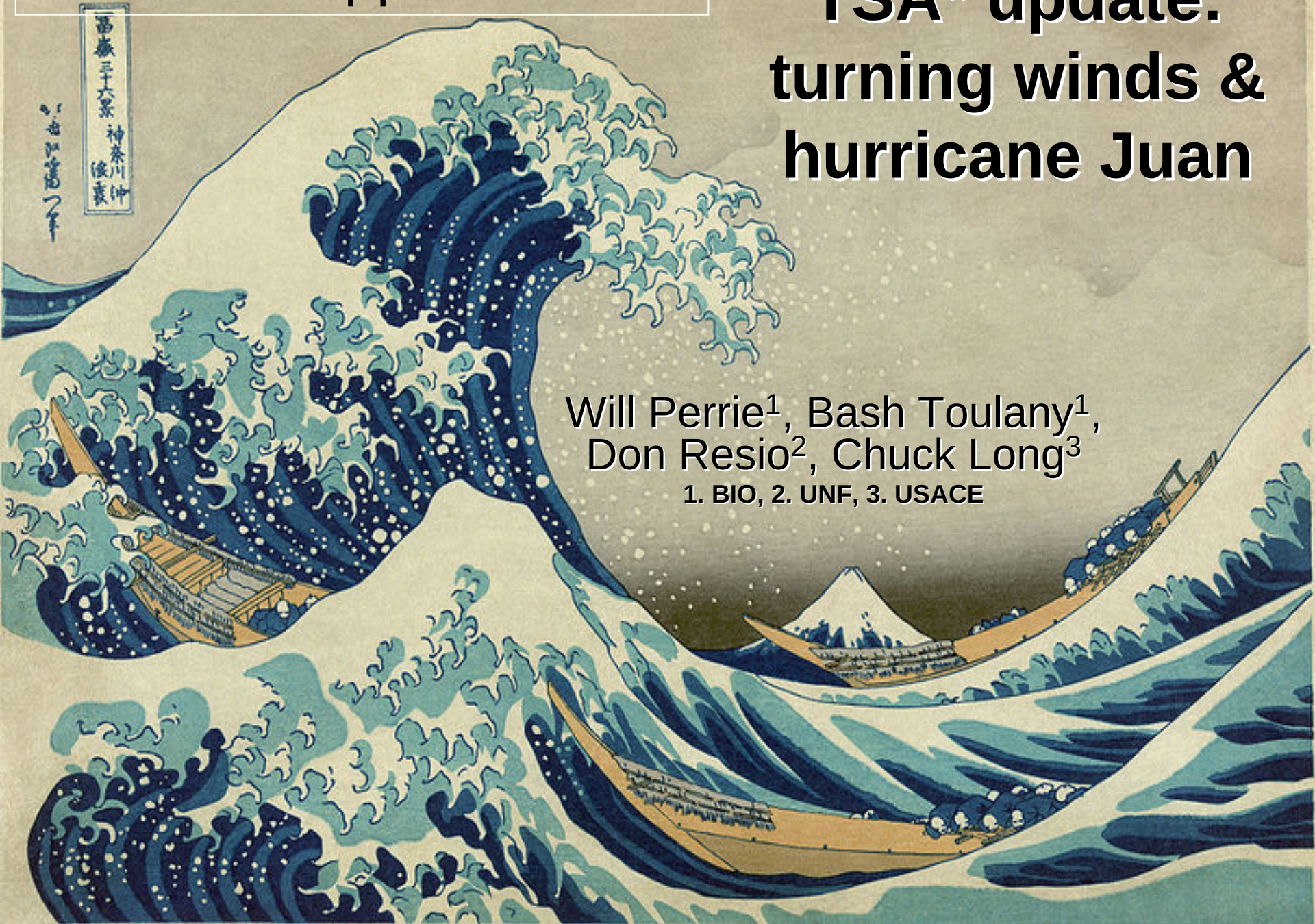


*two scale approximation

TSA* update: turning winds & hurricane Juan

Will Perrie¹, Bash Toulany¹,
Don Resio², Chuck Long³

1. BIO, 2. UNF, 3. USACE



Outline

- TSA background
- fetch-limited growth and TSA characteristics
- turning winds e.g. passing fronts, hurricanes
- modified TSA
- example of hurricane Juan (2003)
- conclusions

Summary / Conclusions

1. original TSA works for simple growing wind-generated waves
2. doesn't work so well multi-peak spectra
3. can generalize by multiple broad-scale terms
4. hypothetical and real data
5. tuning? WAMcycle3 ? Tolman/ Chalikov ?

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

$$\begin{aligned} S_{nl} &= \frac{dN_1}{dt} \\ &= \iiint [N_1 N_3 (N_4 - N_2) + N_2 N_4 (N_3 - N_1)] C(\mathbf{k}_1, \mathbf{k}_2, \mathbf{k}_3, \mathbf{k}_4) \\ &\quad \delta(\mathbf{k}_1 + \mathbf{k}_2 - \mathbf{k}_3 - \mathbf{k}_4) \delta(\omega_1 + \omega_2 - \omega_3 - \omega_4) d\mathbf{k}_2 d\mathbf{k}_3 d\mathbf{k}_4 \end{aligned}$$

For the change in spectral action density at N_1 (e.g. at $\mathbf{k}_1$) due to wave-wave interactions involving $\mathbf{k}_2$, $\mathbf{k}_3$ and $\mathbf{k}_4$) - Hasselmann (1962), Zakharov (1966)

TSA – two scale approximation

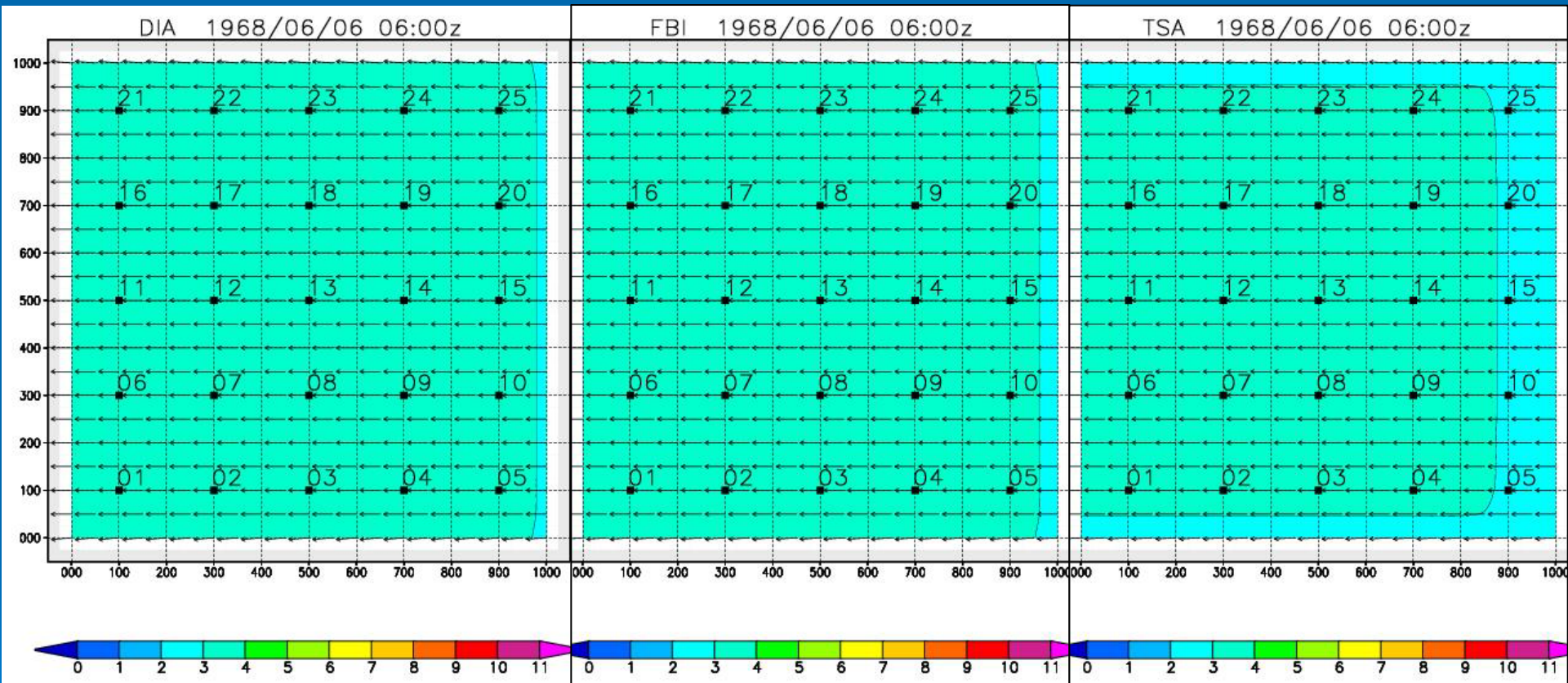
$$N_i = N_{i [\text{broad-scale}]} + N_{i [\text{local-scale}]}$$

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

[Resio and Perrie 2008; Perrie & Resio 2009]

Fetch-limited wave growth

6 hr



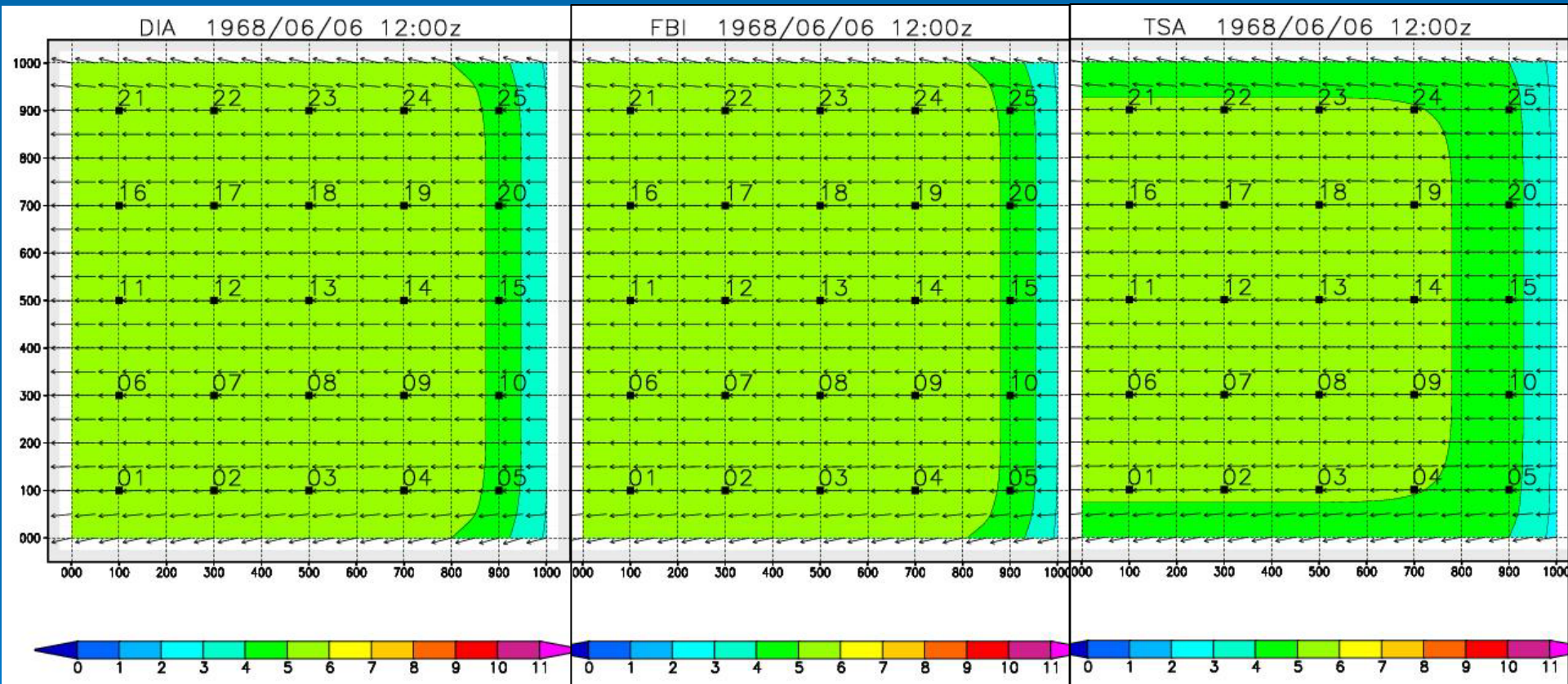
DIA

FBI

TSA

Fetch-limited wave growth

12 hr



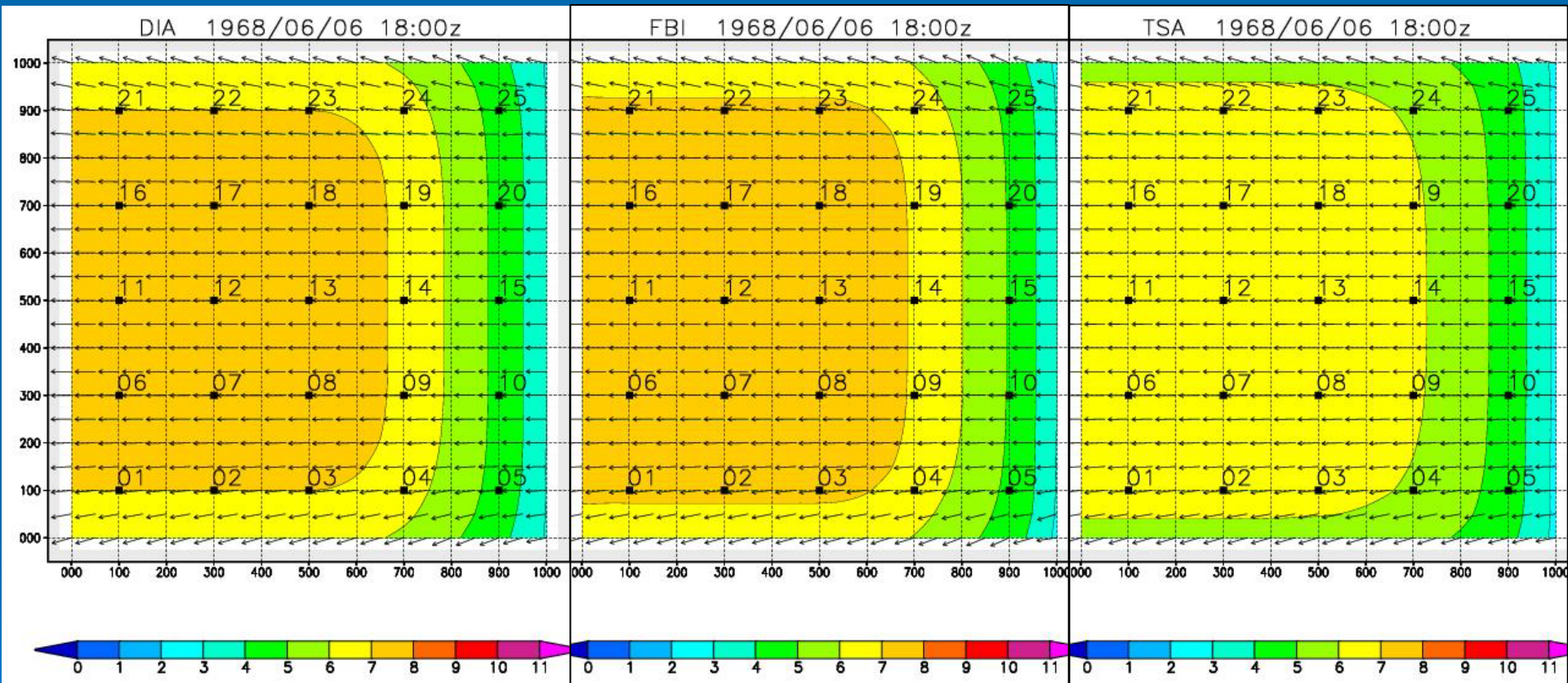
DIA

FBI

TSA

Fetch-limited wave growth

18 hr



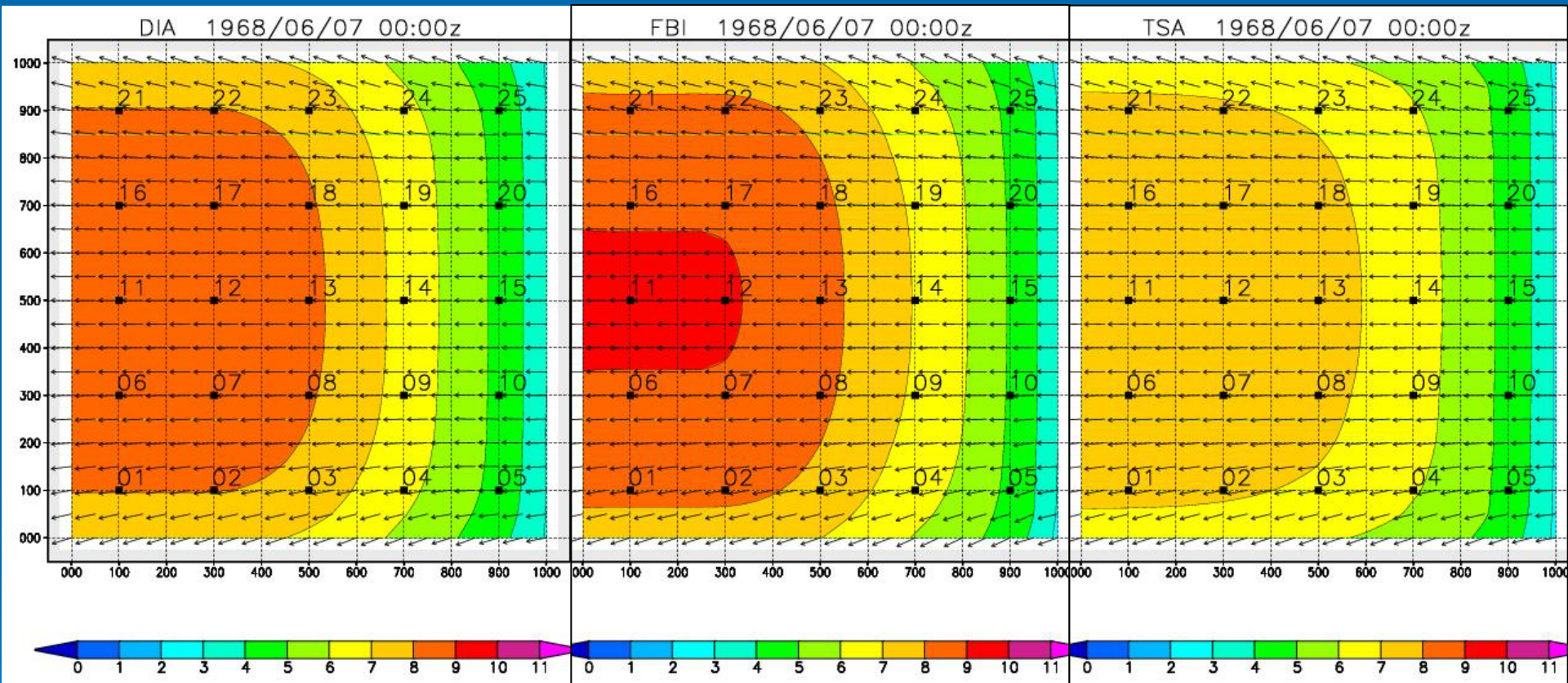
DIA

FBI

TSA

Fetch-limited wave growth

24 hr



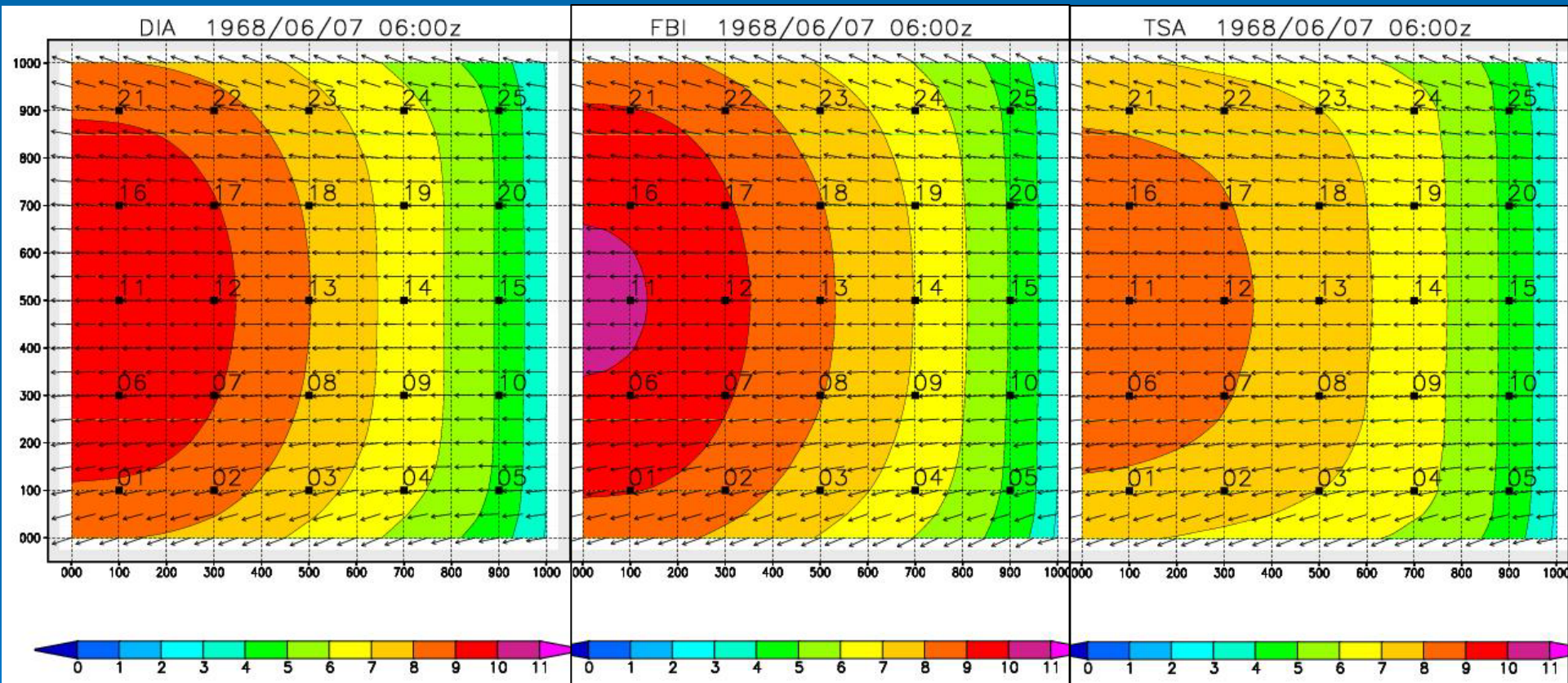
DIA

FBI

TSA

Fetch-limited wave growth

30 hr



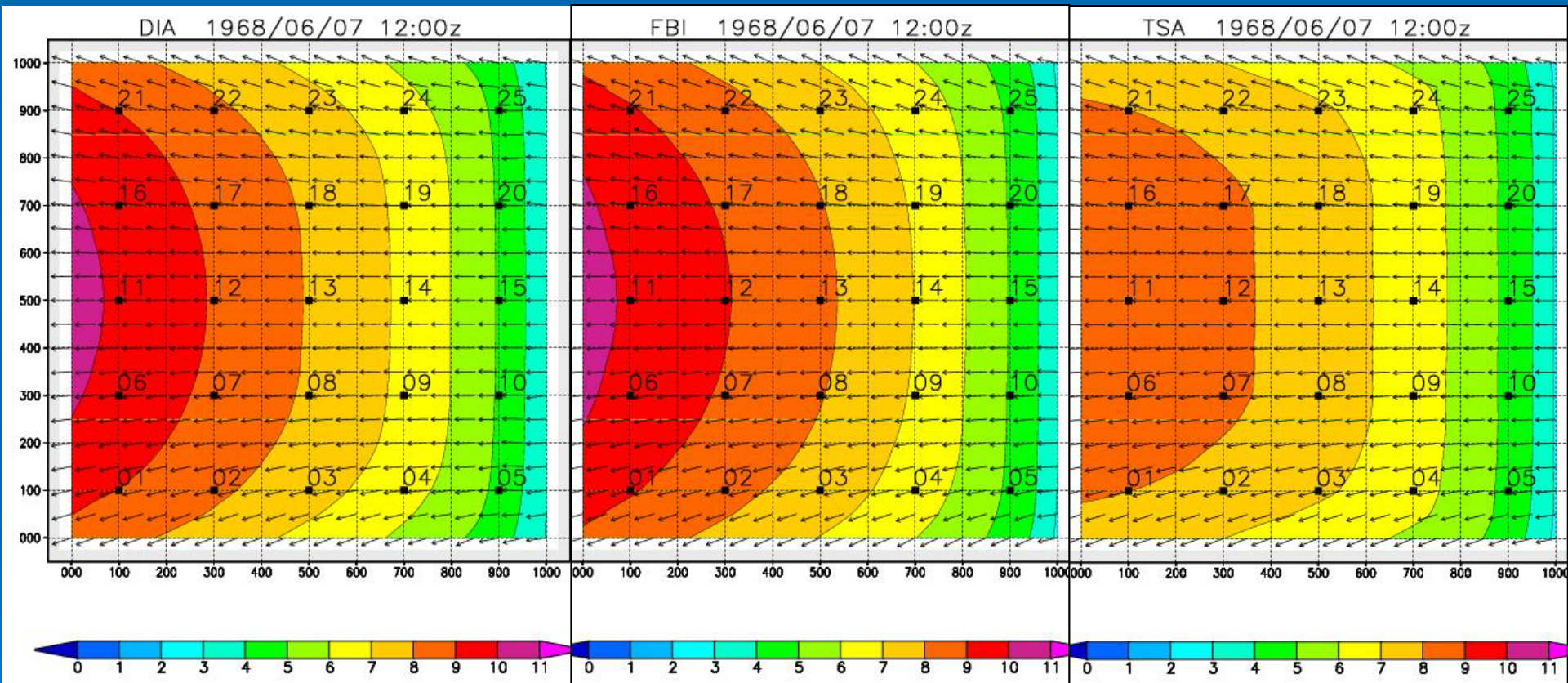
DIA

FBI

TSA

Fetch-limited wave growth

36 hr



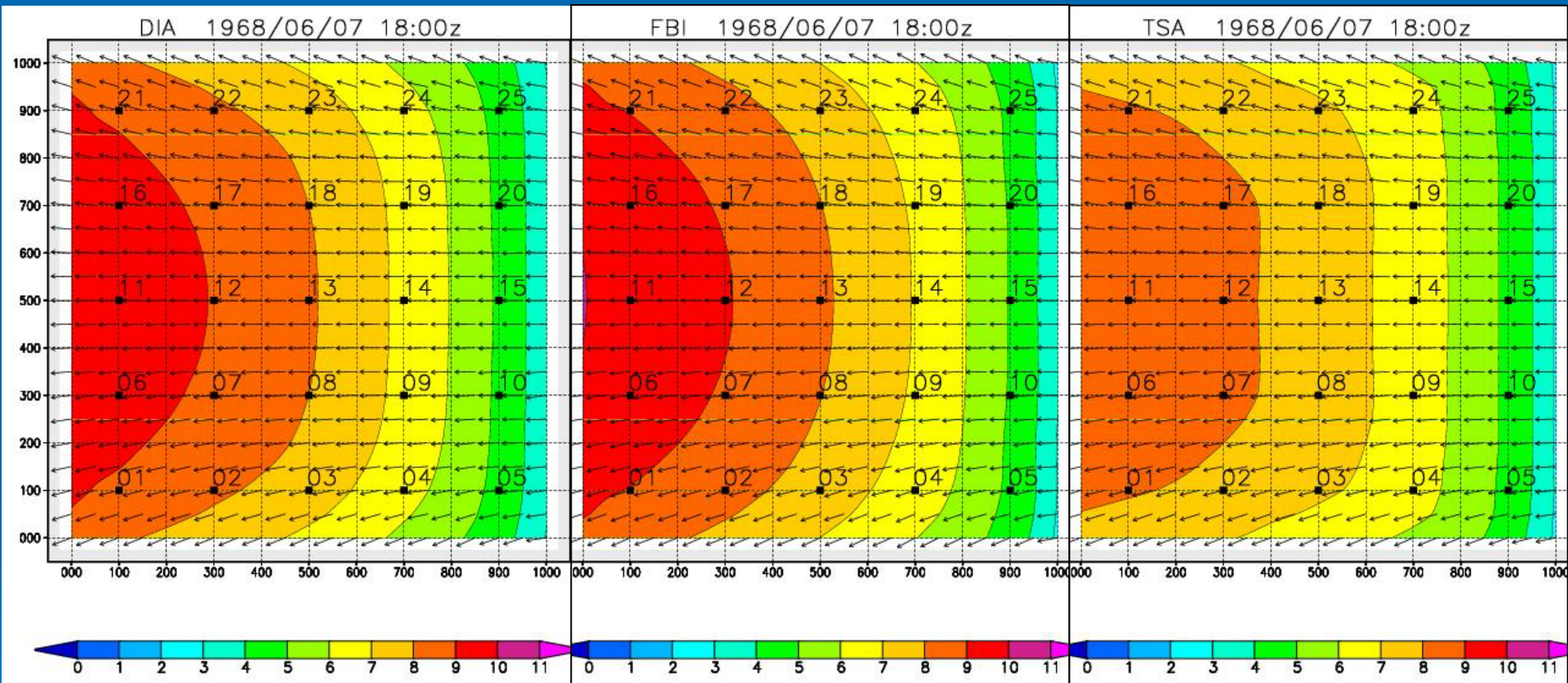
DIA

FBI

TSA

Fetch-limited wave growth

42 hr

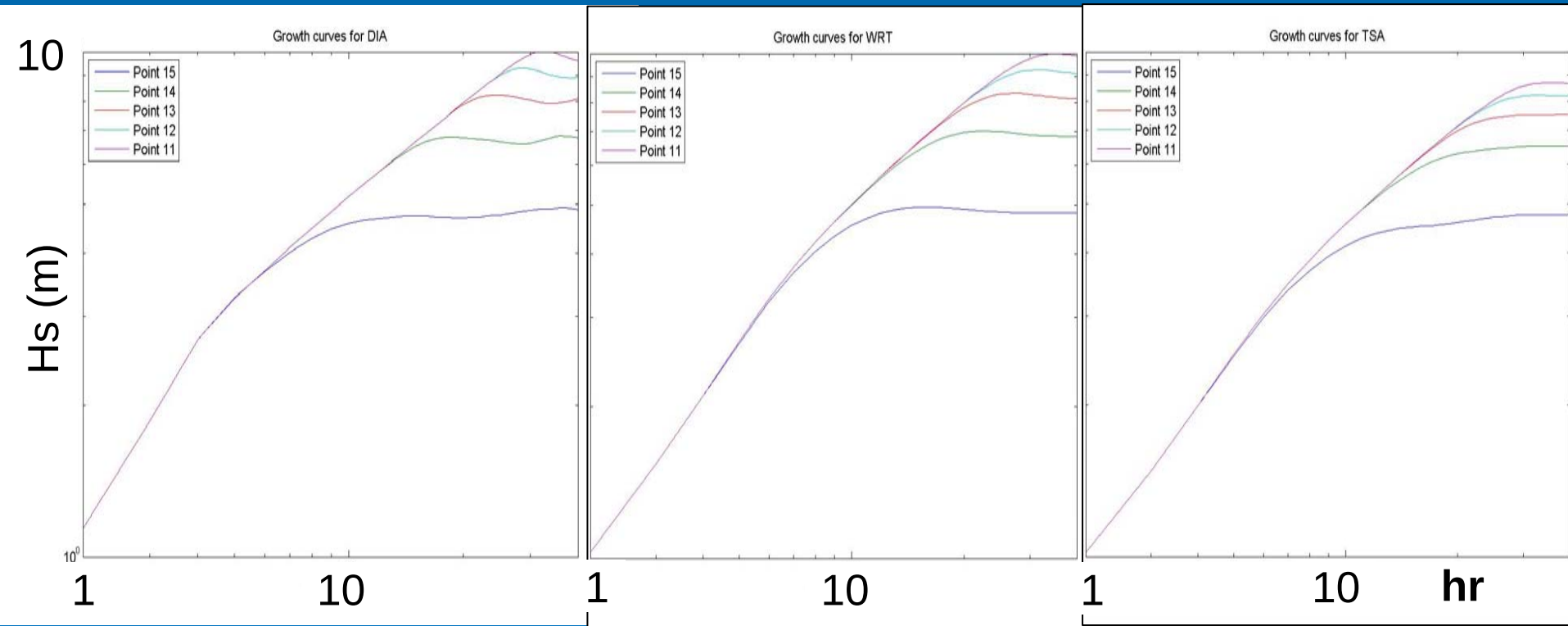


DIA

FBI

TSA

Growth Curves



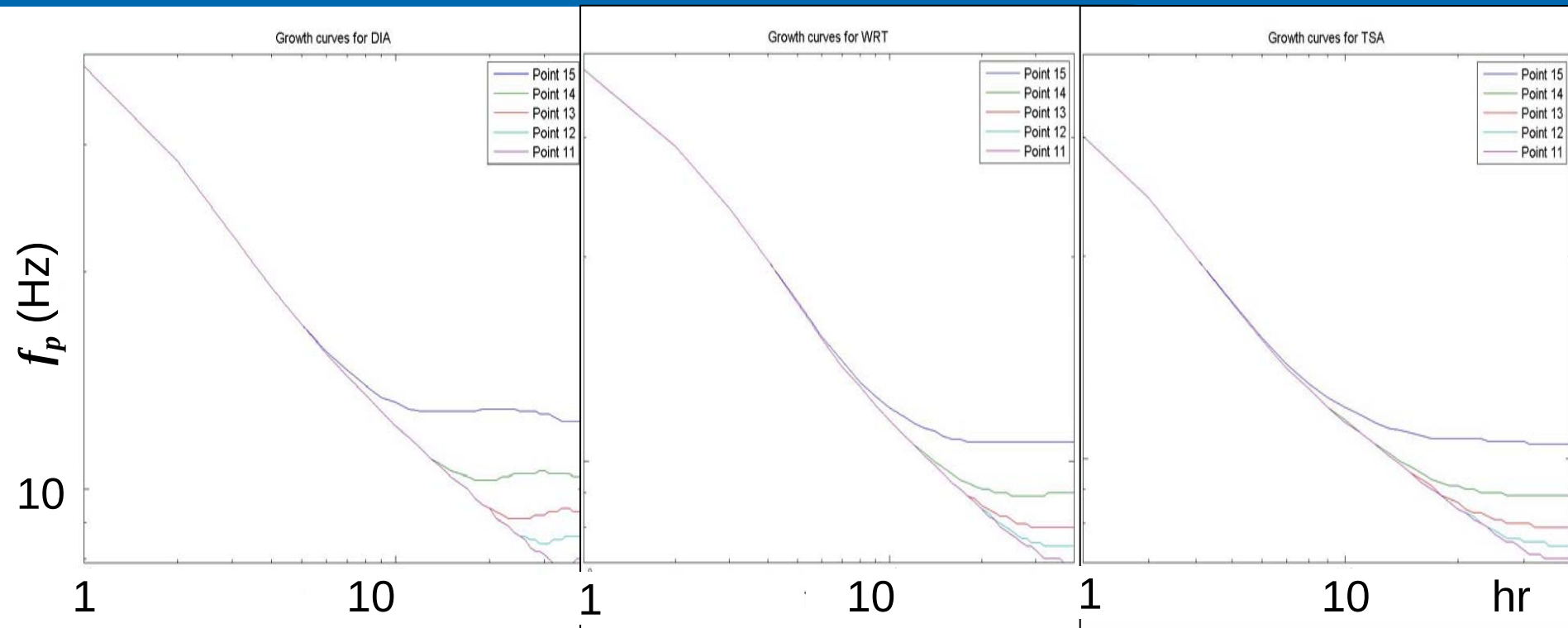
DIA

FBI

TSA

Growth Curves

➤ Now turn winds by 90° for the next 48 hr

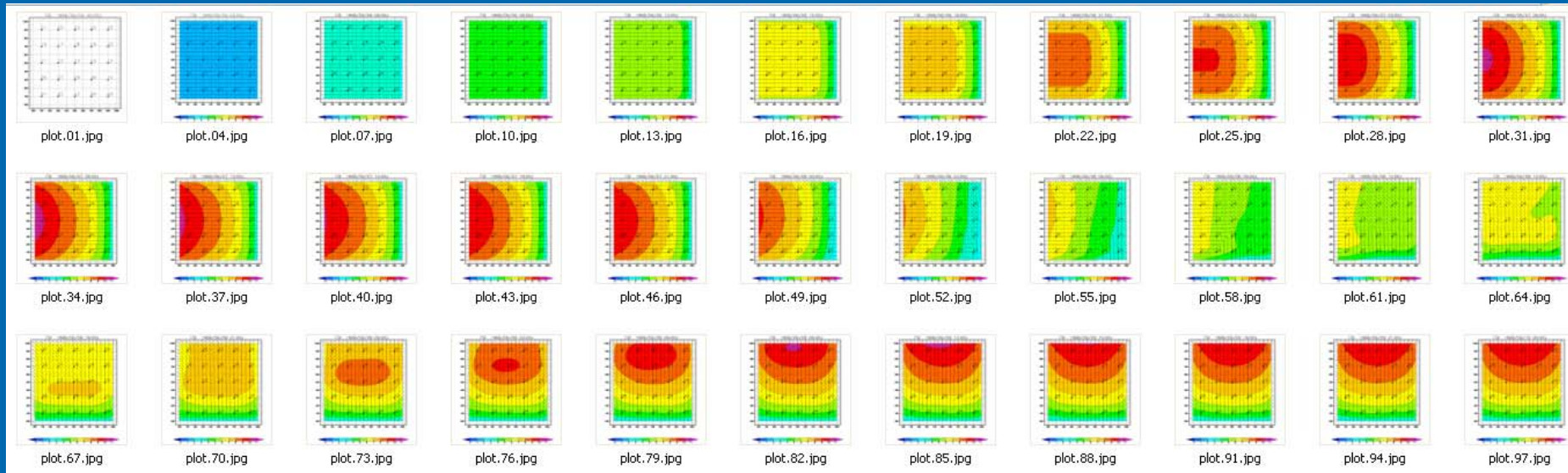


DIA

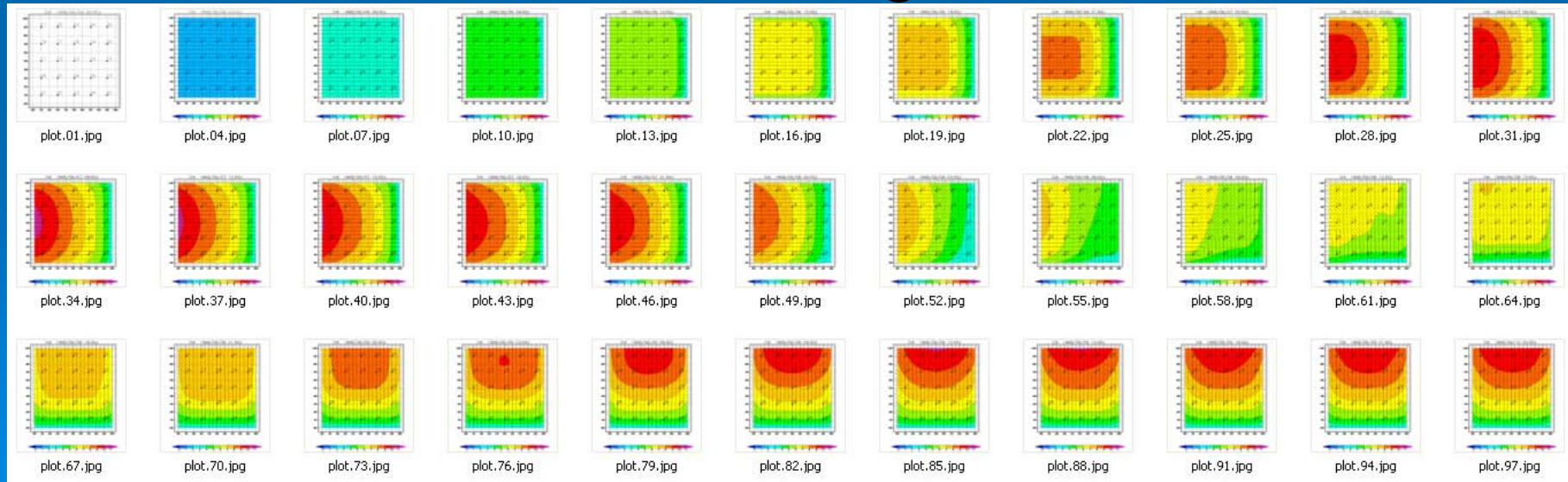
FBI

TSA

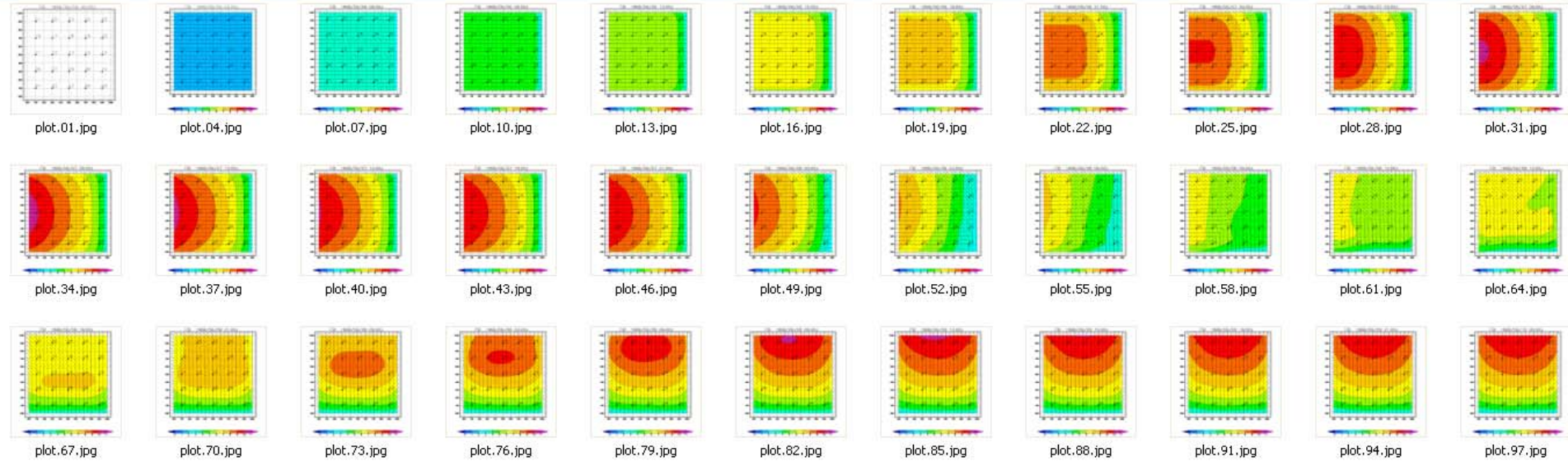
WRT-exact 90° turning winds



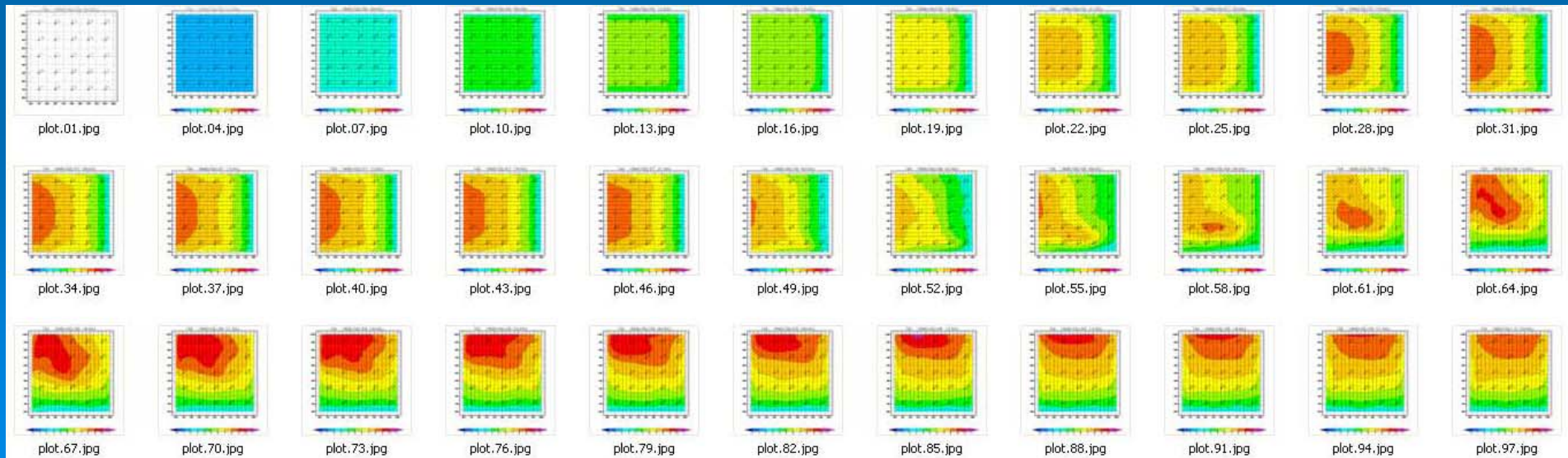
DIA 90° turning winds



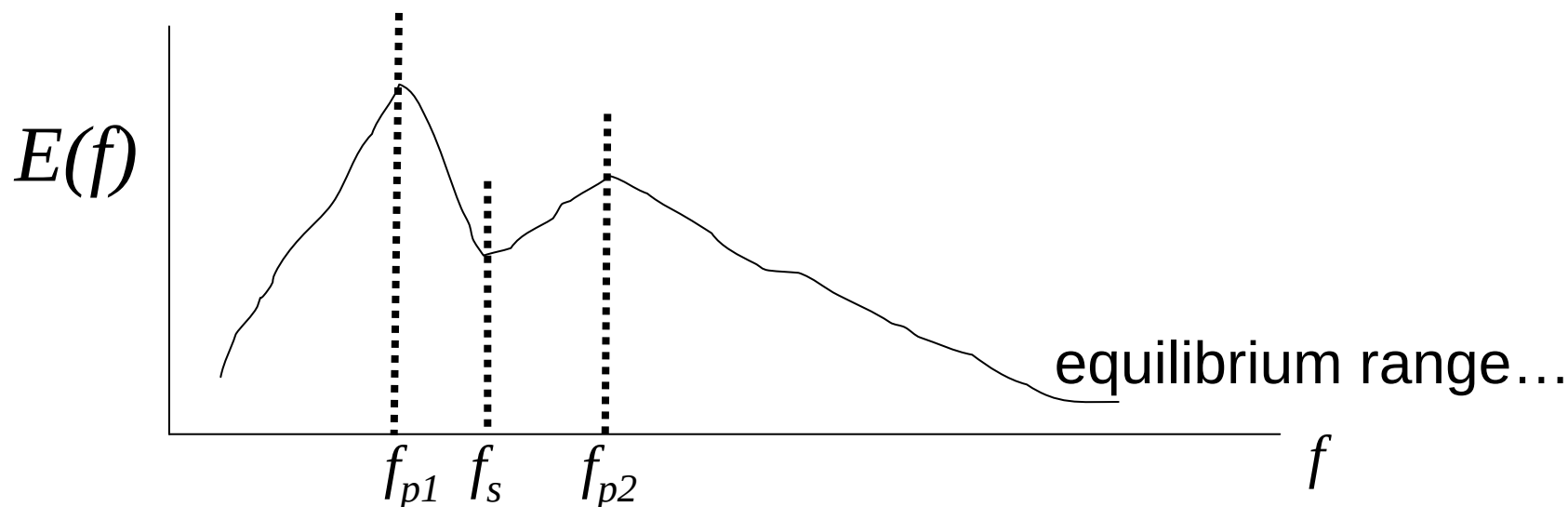
WRT-exact 90° turning winds



original TSA 90° turning winds



Multiple spectral peaks



Broad-scale term parameterization...?

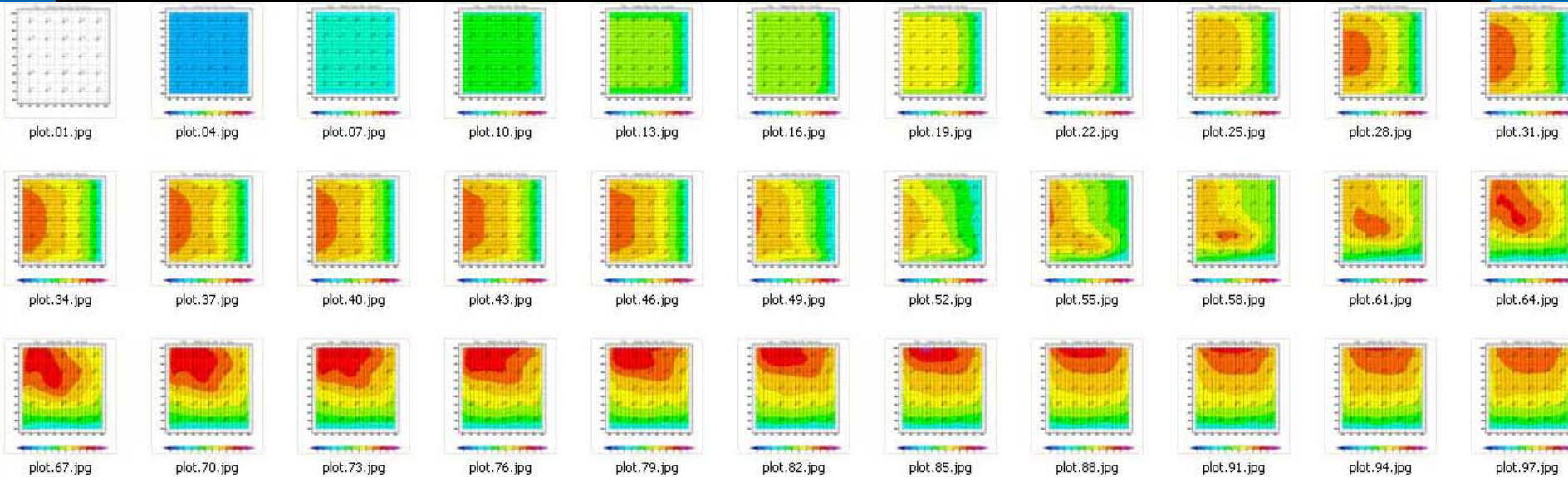
$$F(k)_{\text{Norm}} = F(k) \times k^{2.5} / \beta \quad [\text{Resio\&Perrie, 1989; Resio et al. 2004...}]$$

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

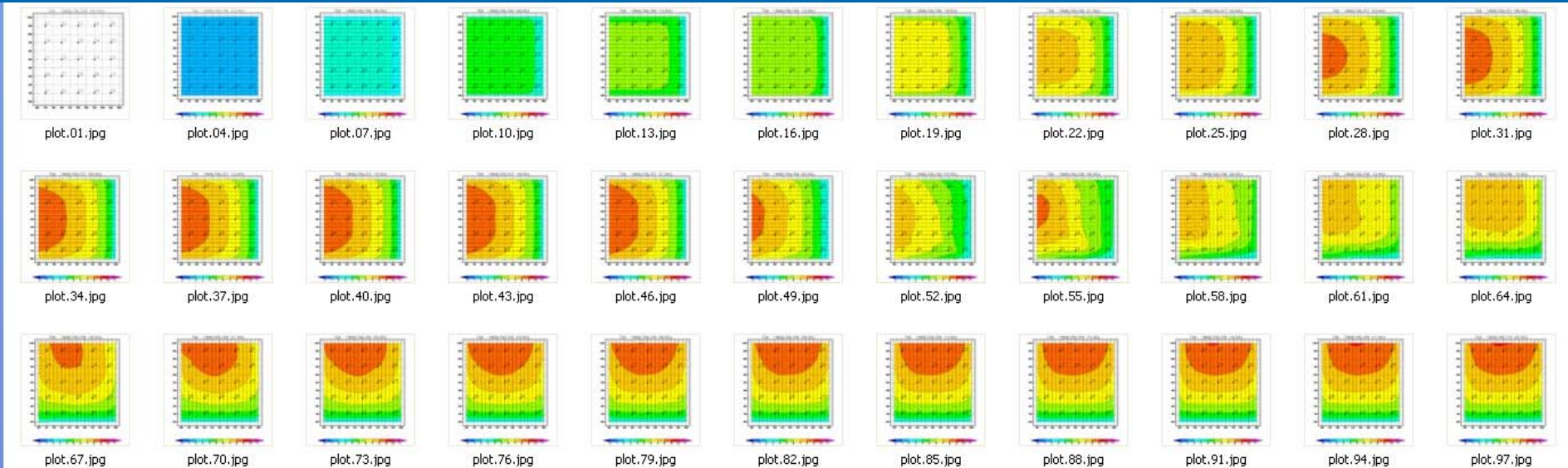
But equilibrium range is hard to define when f_{p1} and f_{p2} are close...

So let $\beta = F(k) \times k^{2.5} |_{f_s} \dots$ *for the first peak ...*

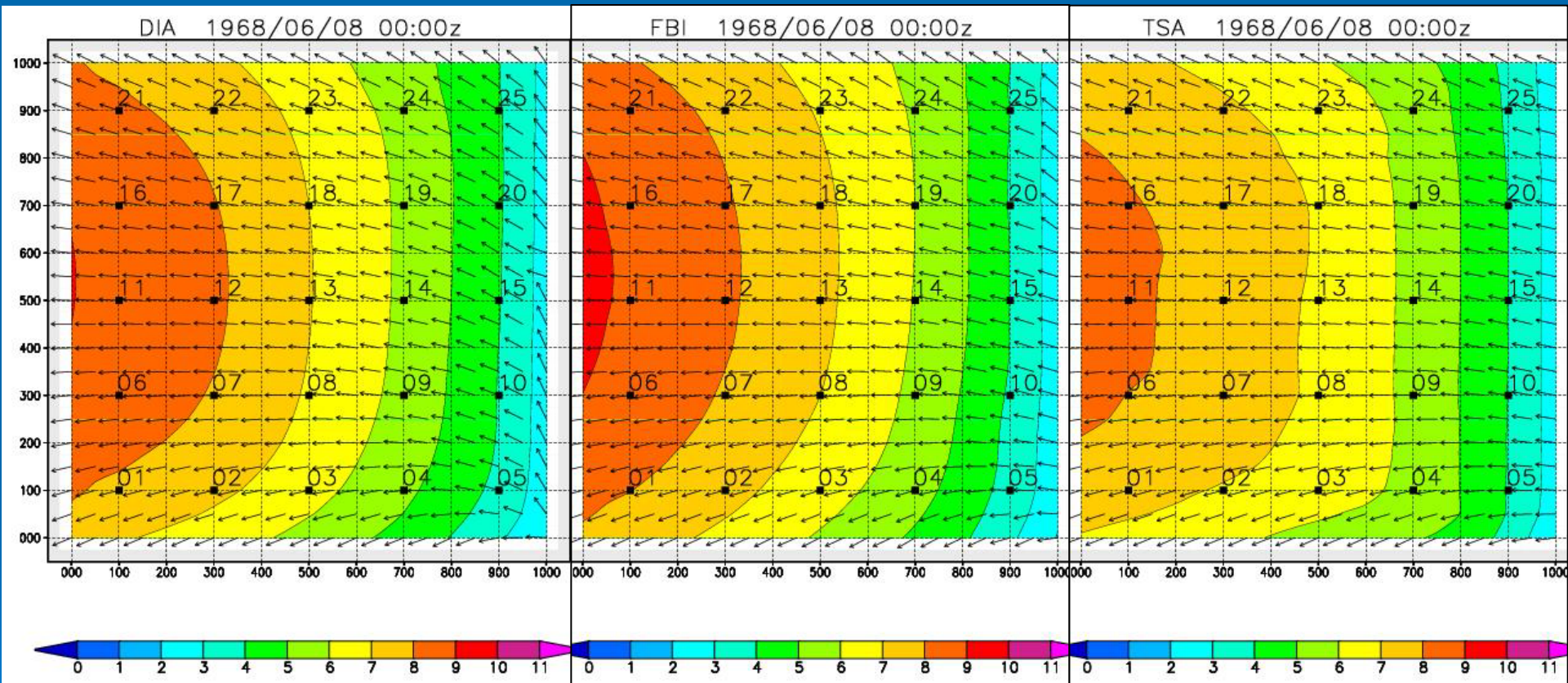
OLD TSA 90° turning winds



NEW TSA 90° turning winds



Turning winds 90°....

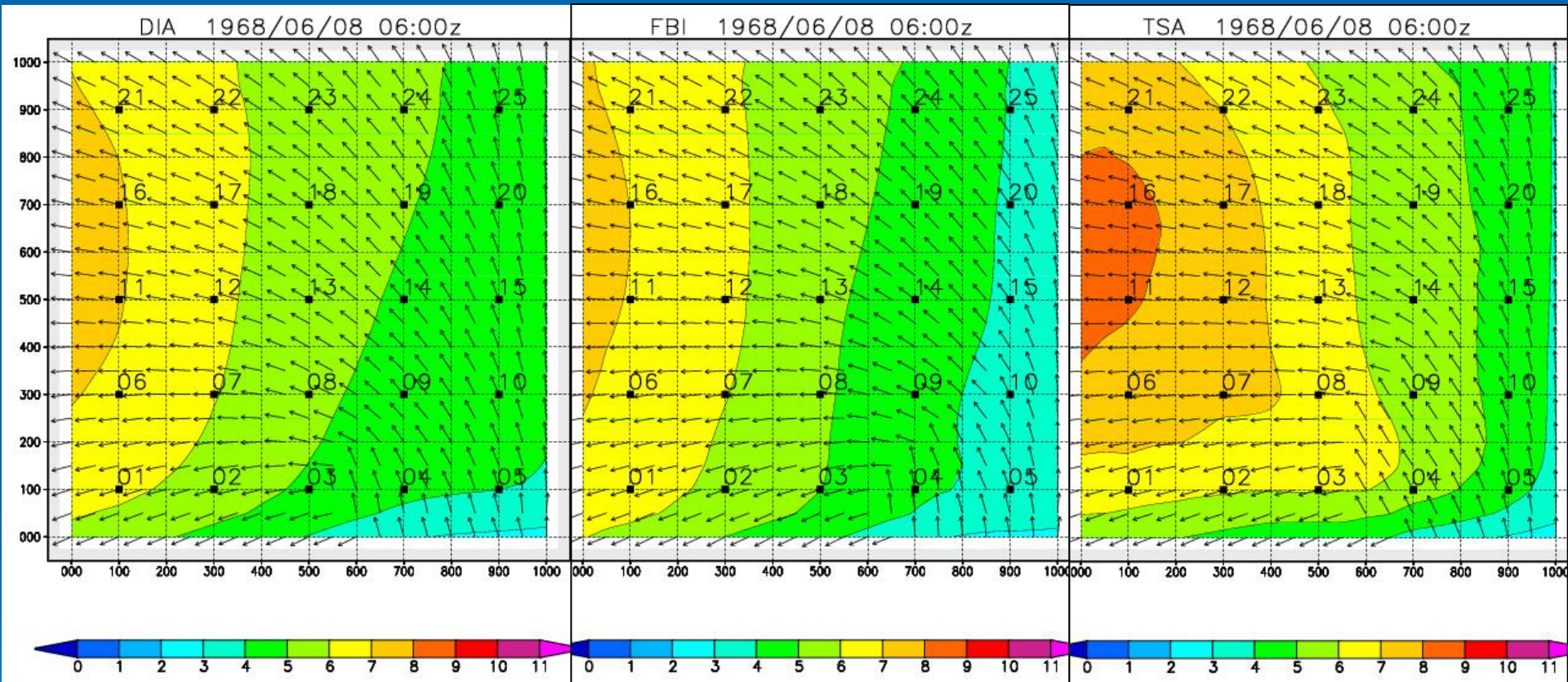


DIA

FBI

TSA

Turning winds + 6 hr

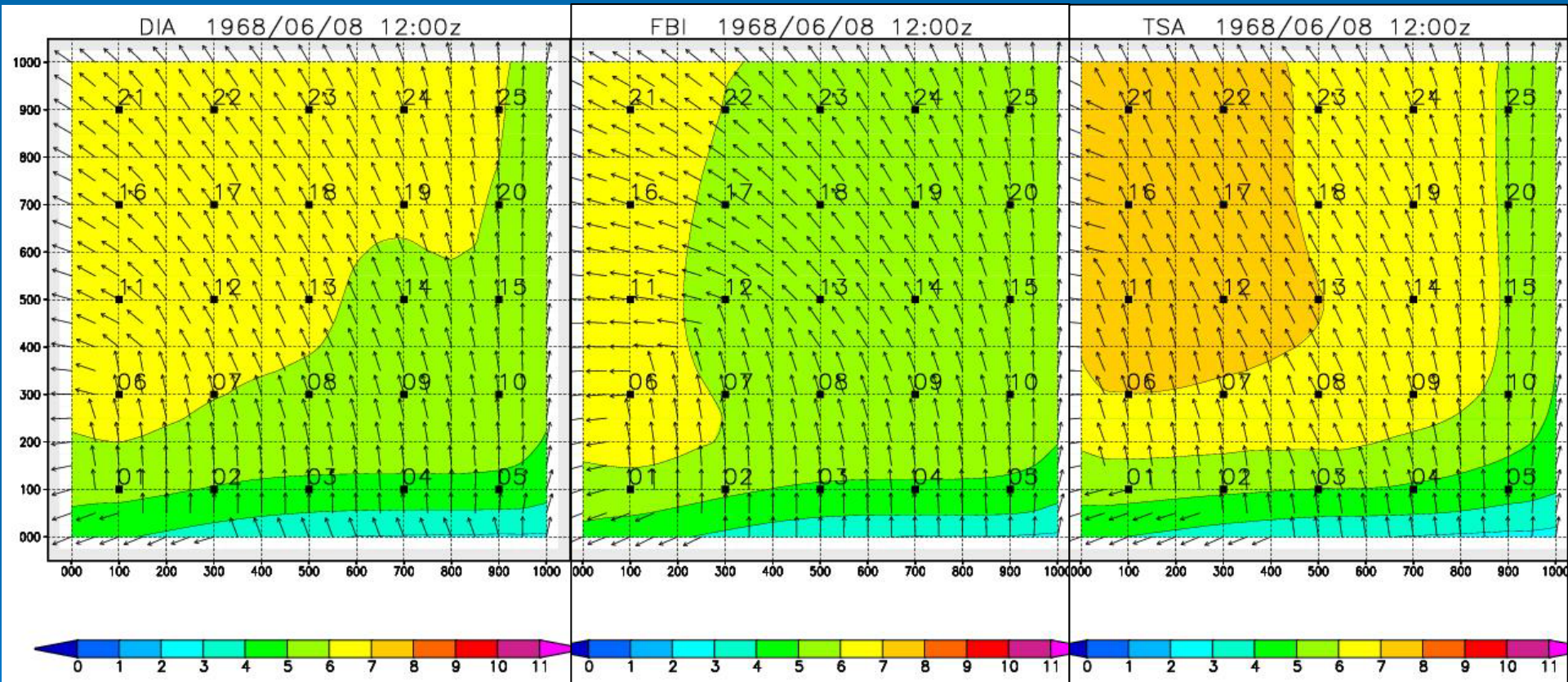


DIA

FBI

TSA

Turning winds + 12 hr

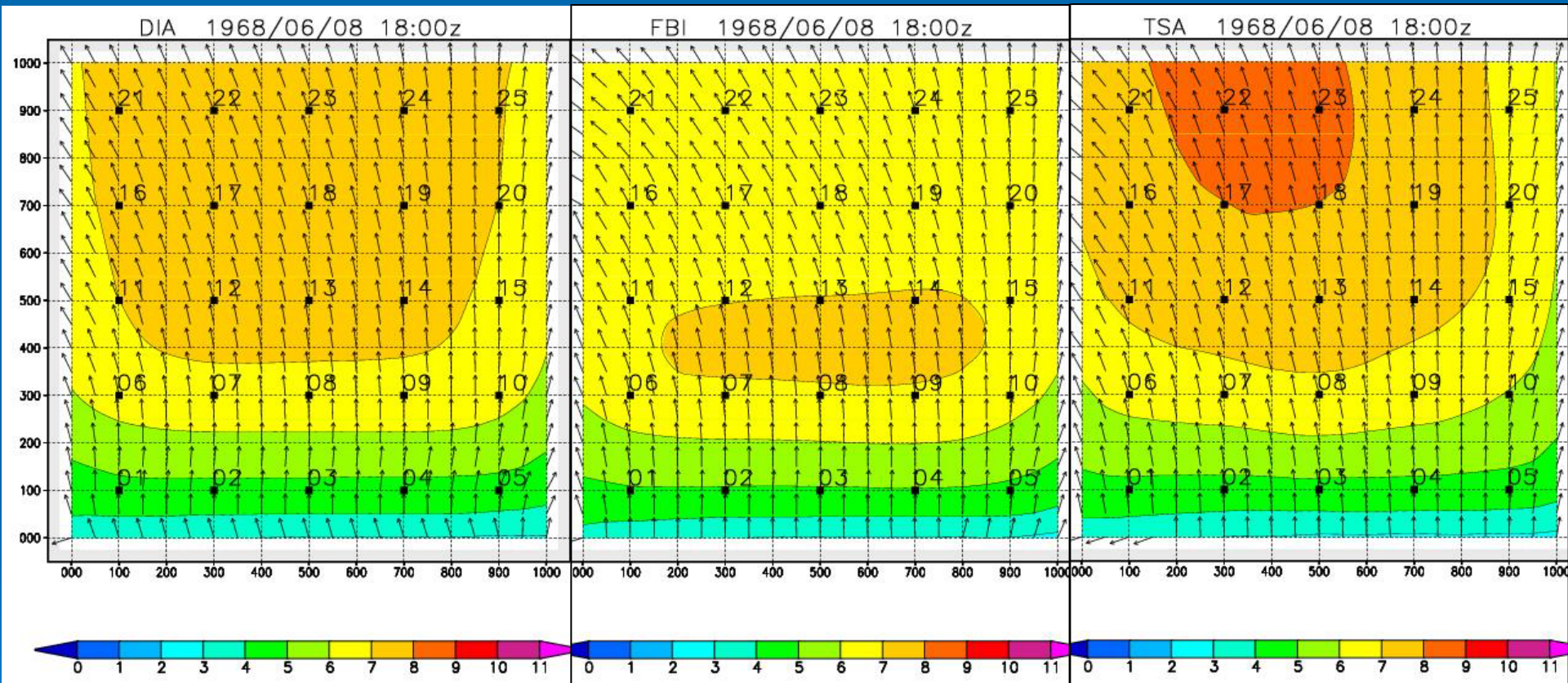


DIA

FBI

TSA

Turning winds + 18 hr

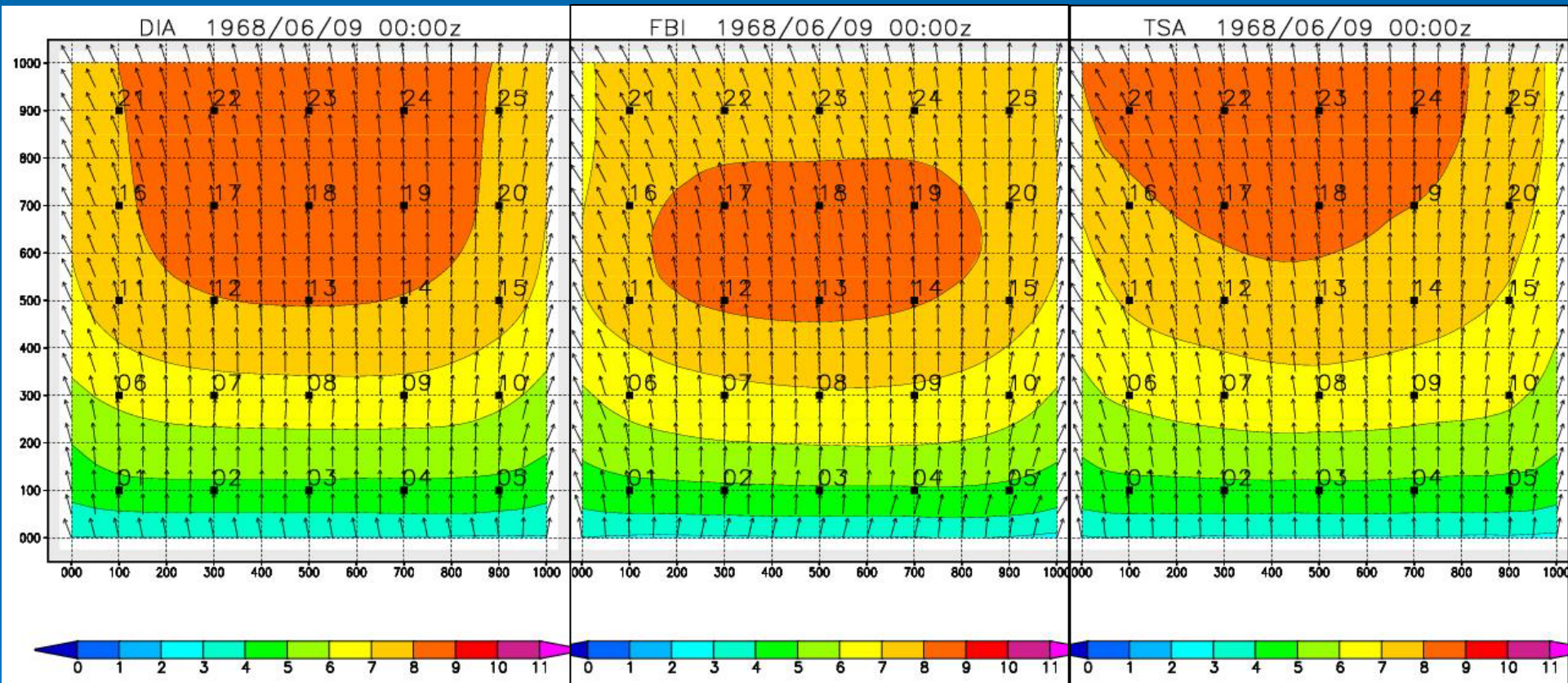


DIA

FBI

TSA

Turning winds + 24 hr

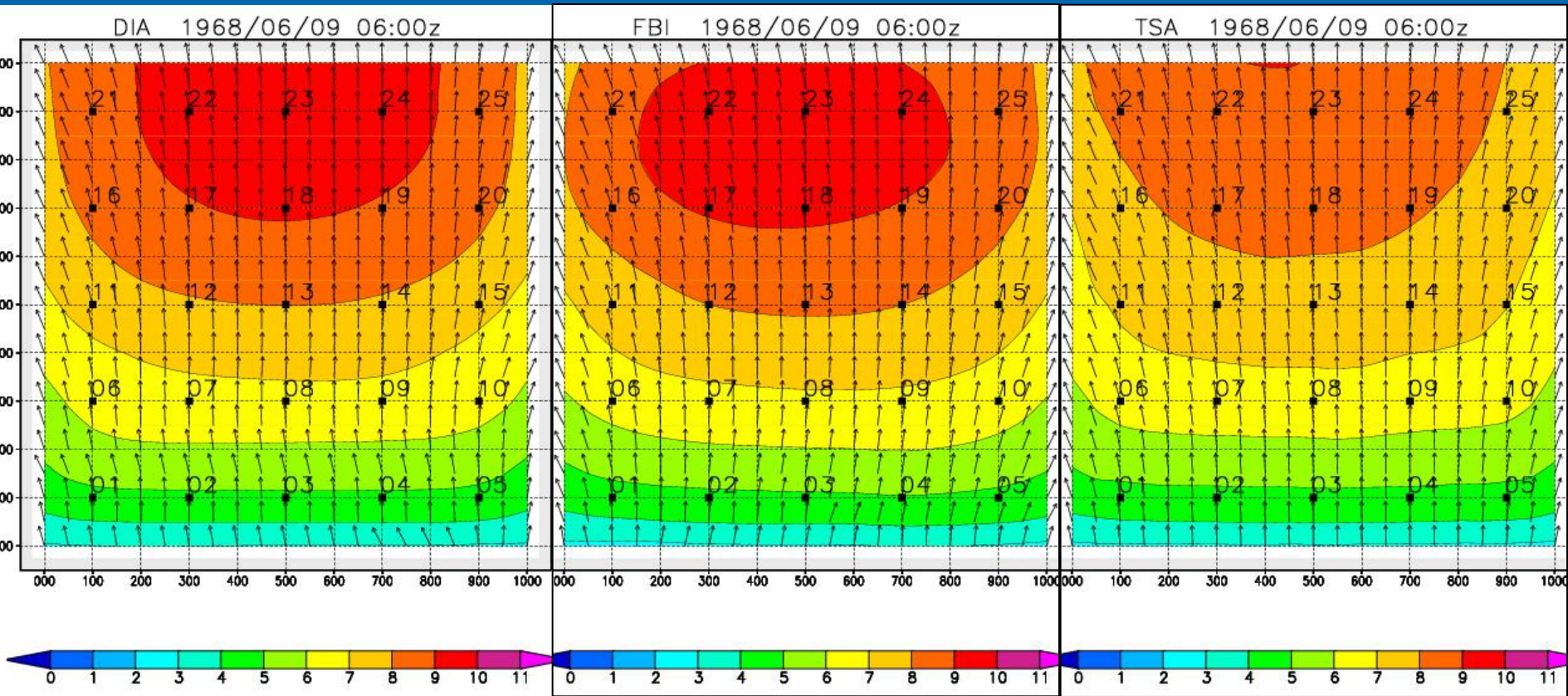


DIA

FBI

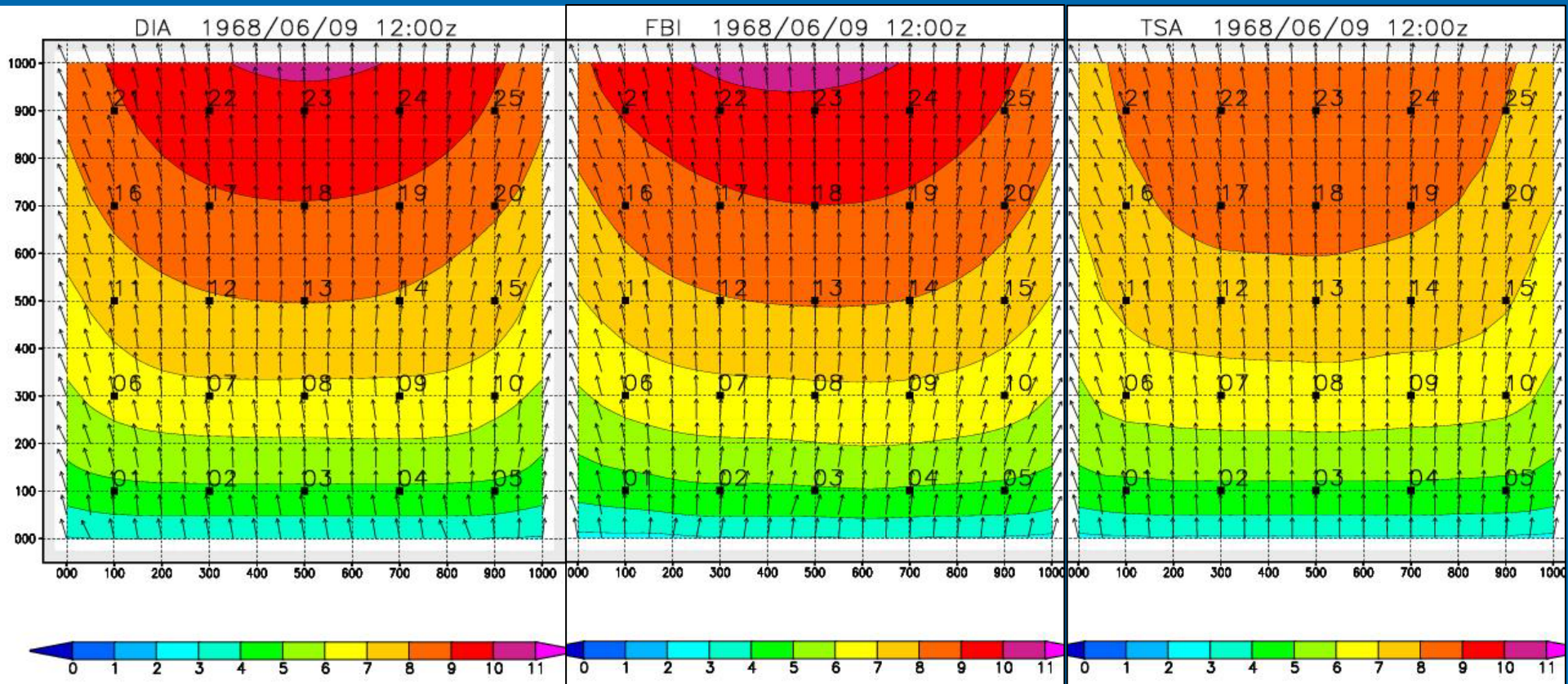
TSA

Turning winds + 30 hr



TSA

Turning winds + 36 hr

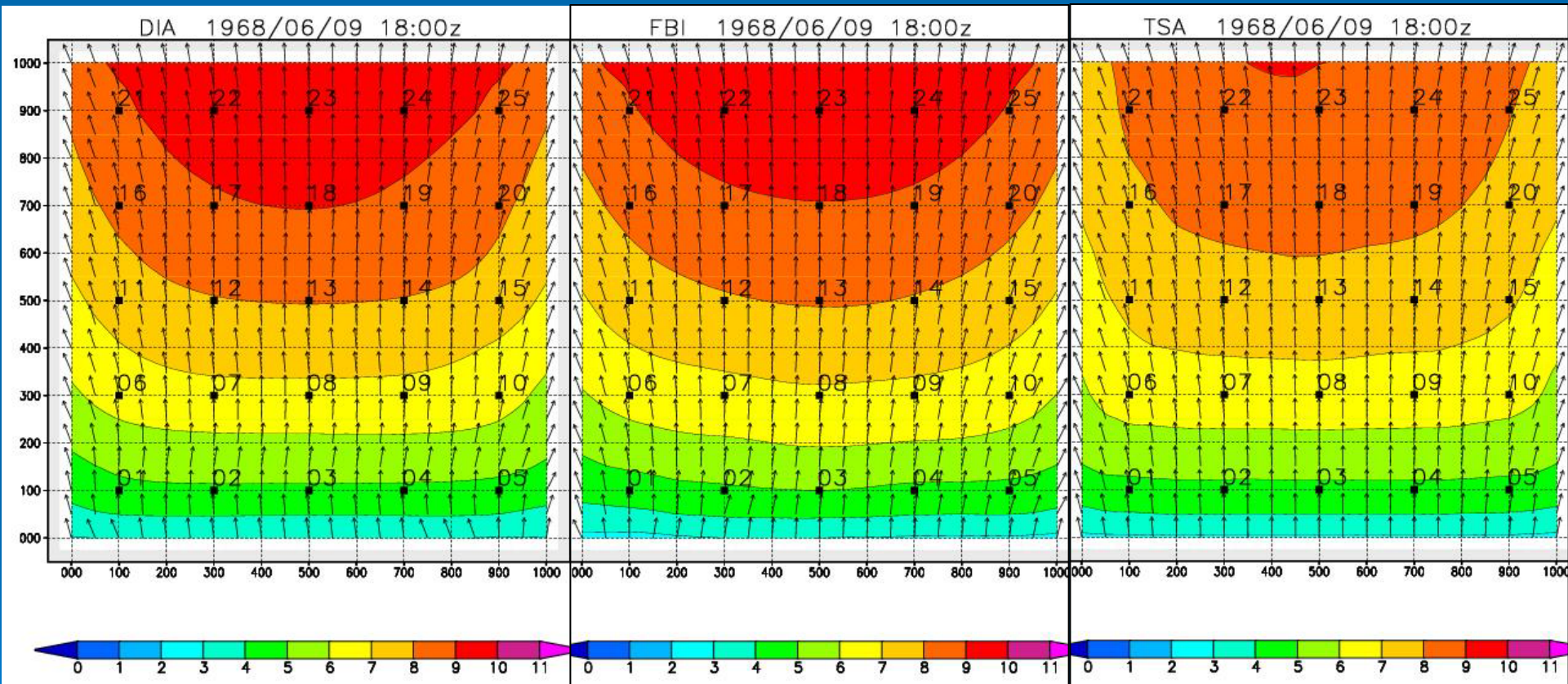


DIA

FBI

TSA

Turning winds + 42 hr

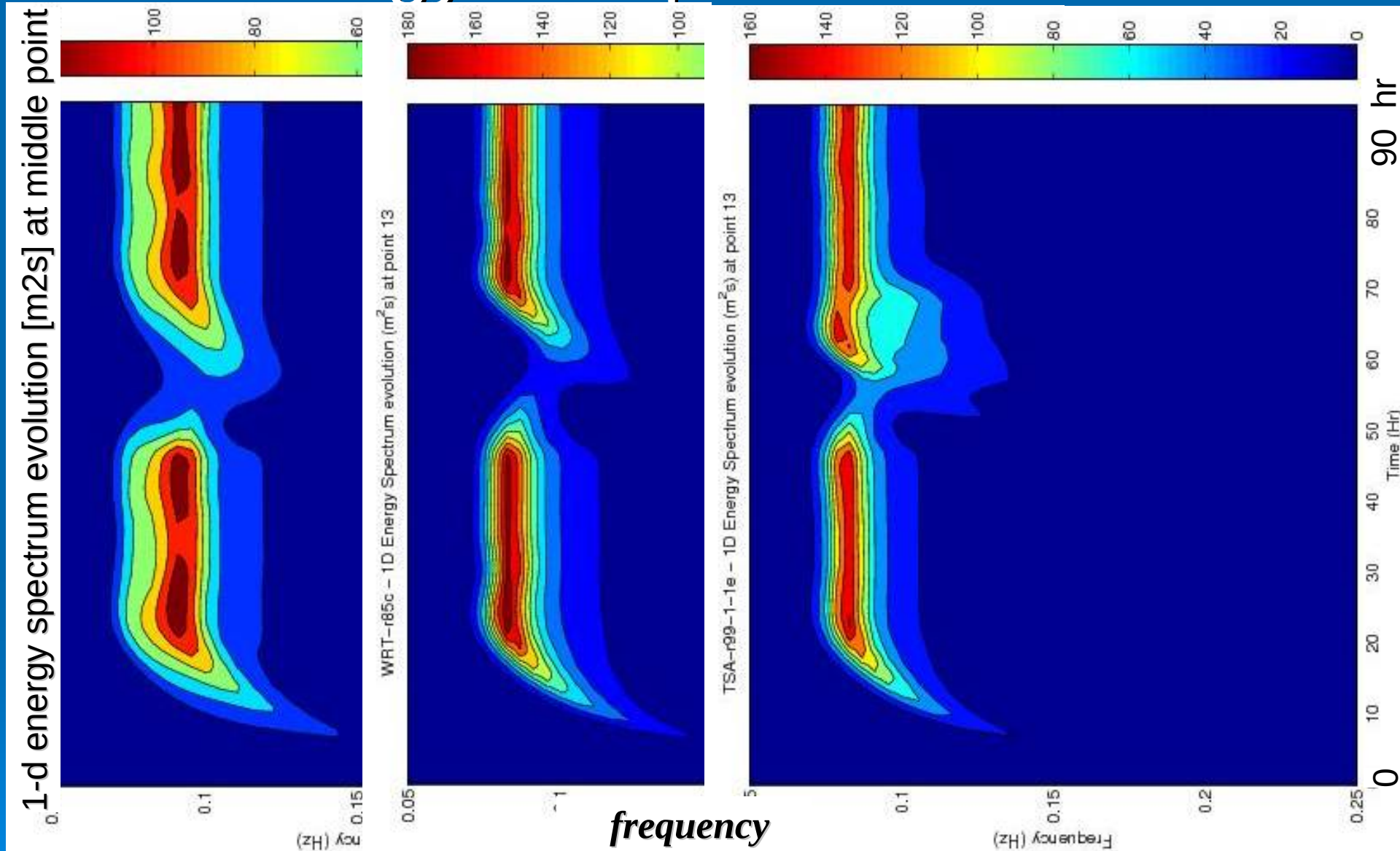


DIA

FBI

TSA

1-d energy: mid-point of box-ocean



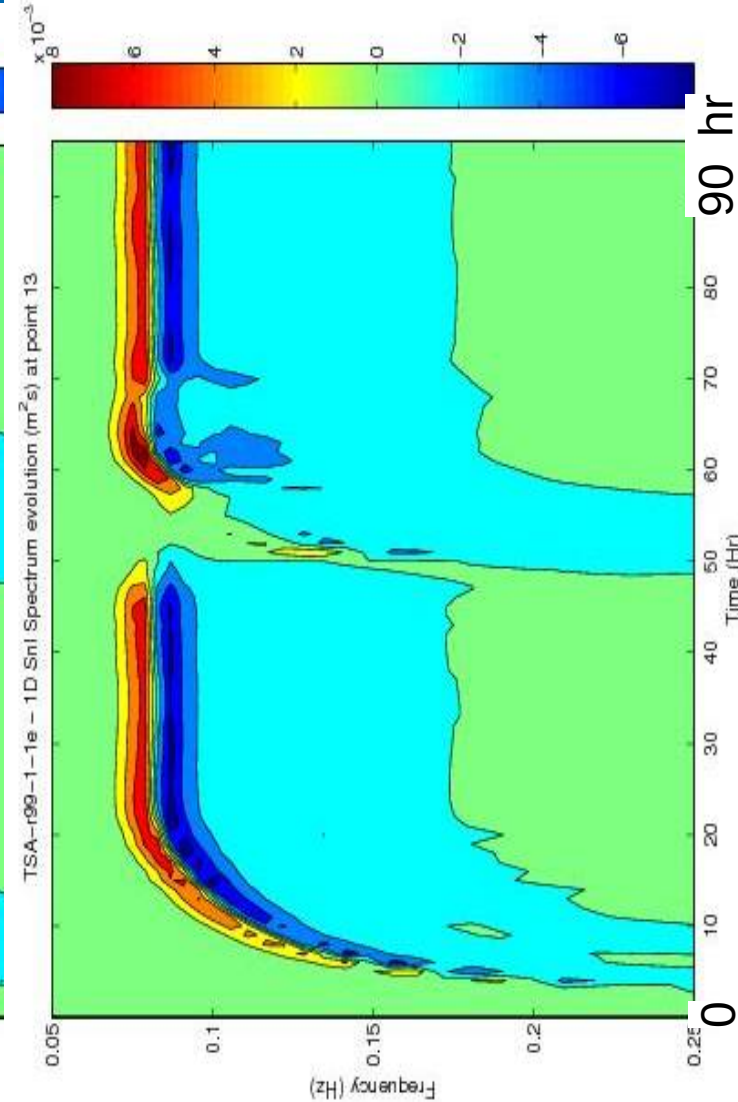
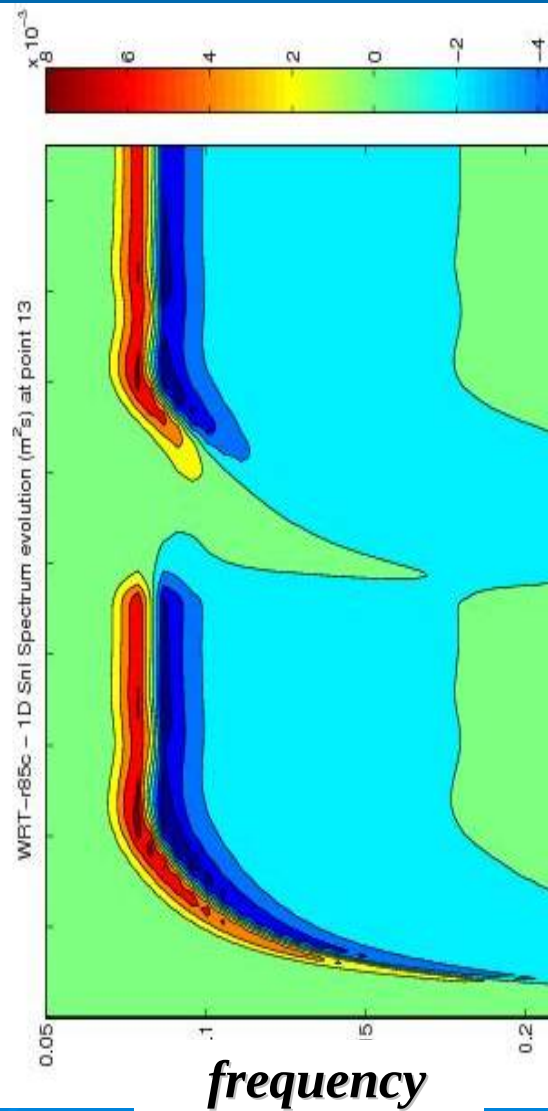
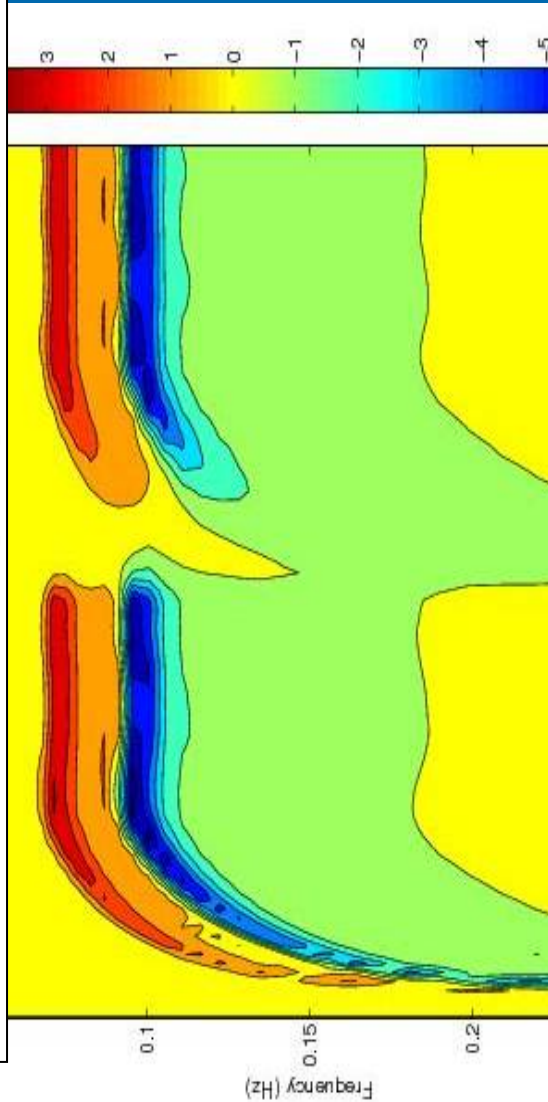
DIA

FBI

TSA

1-d Snl: mid-point of box-ocean ...

1-d Snl evolution [m²s] at middle point



DIA

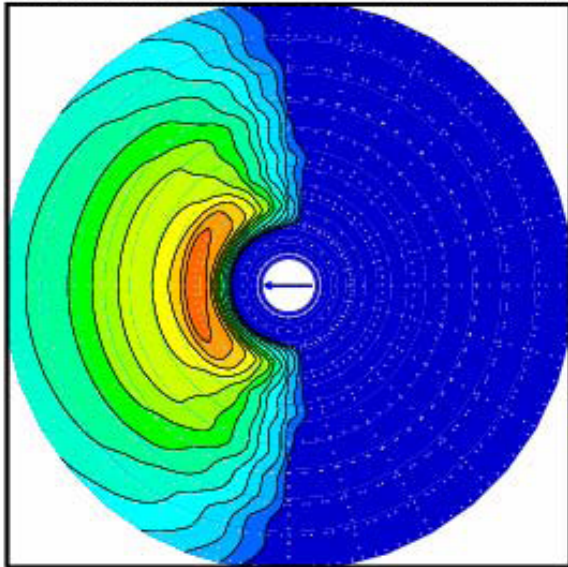
FBI

TSA

Fetch-limited wave growth

6 hr

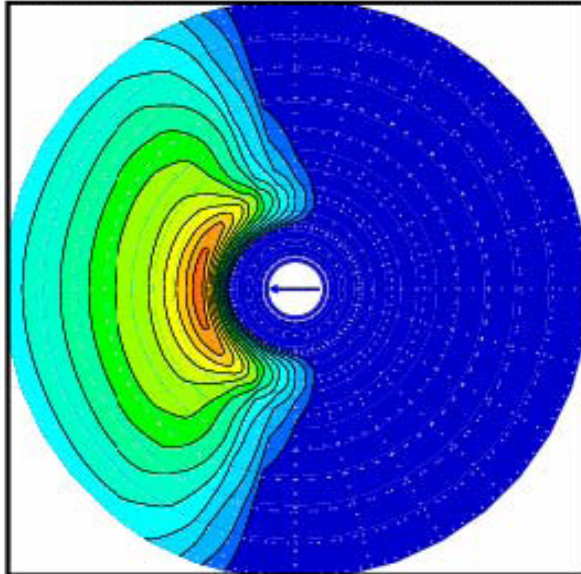
1968/06/06 06z Hs = 3.69m



ww3 U = 20.0m/s

DIA

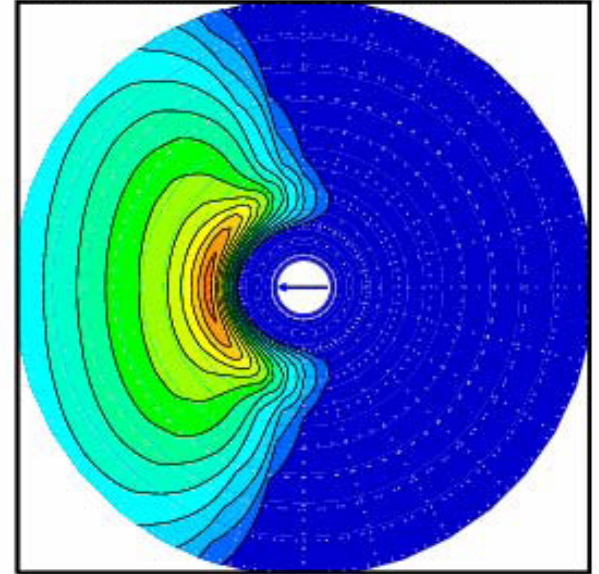
1968/06/06 06z Hs = 3.26m



ww3 U = 20.0m/s

FBI

1968/06/06 06z Hs = 3.03m

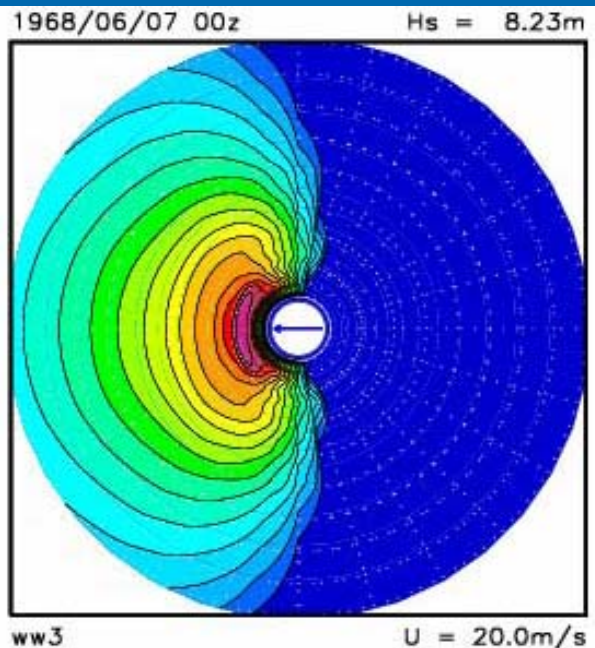


ww3 U = 20.0m/s

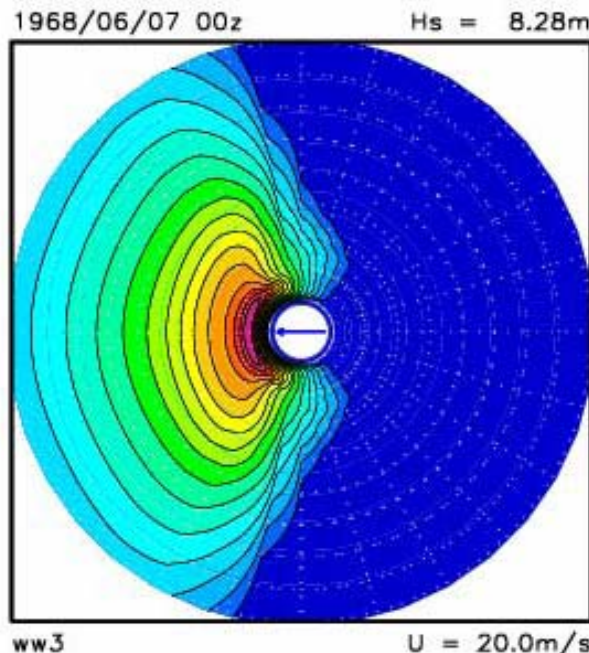
TSA

Fetch-limited wave growth

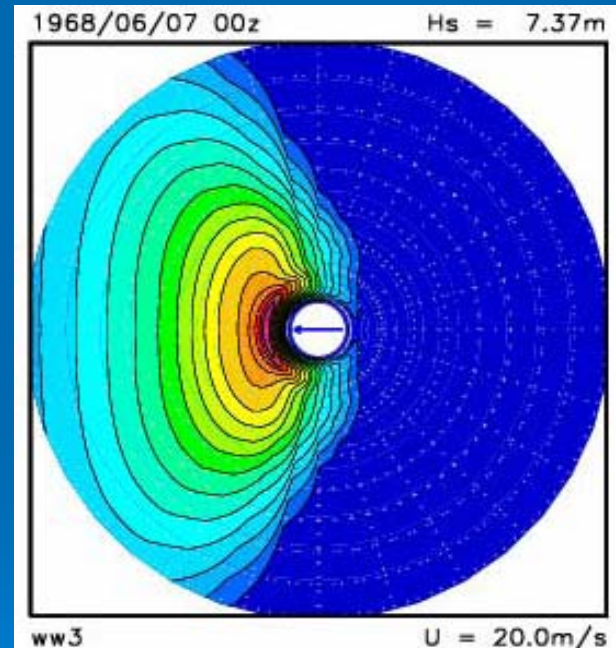
24 hr



DIA



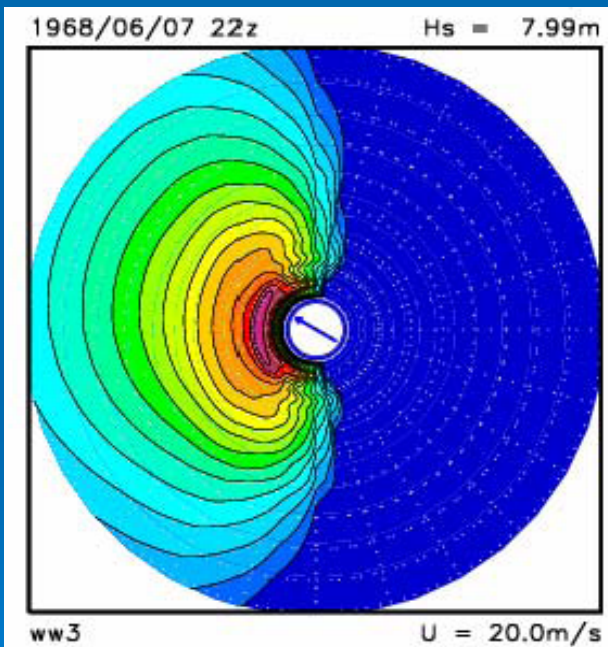
FBI



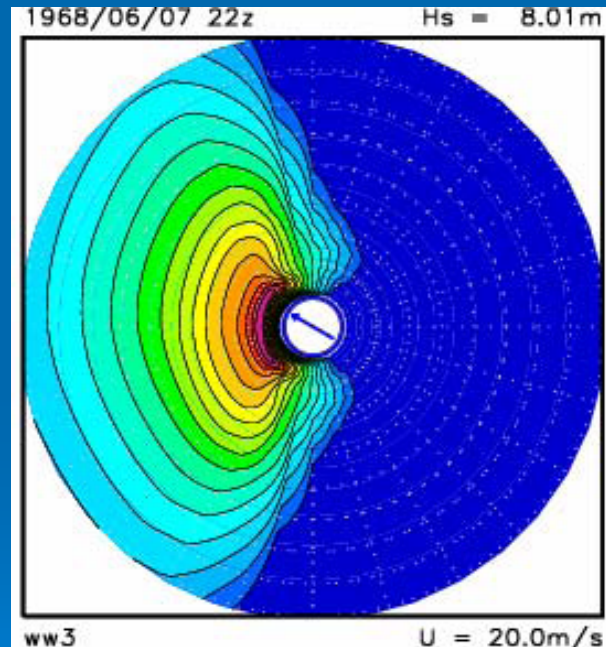
TSA

Fetch-limited wave growth

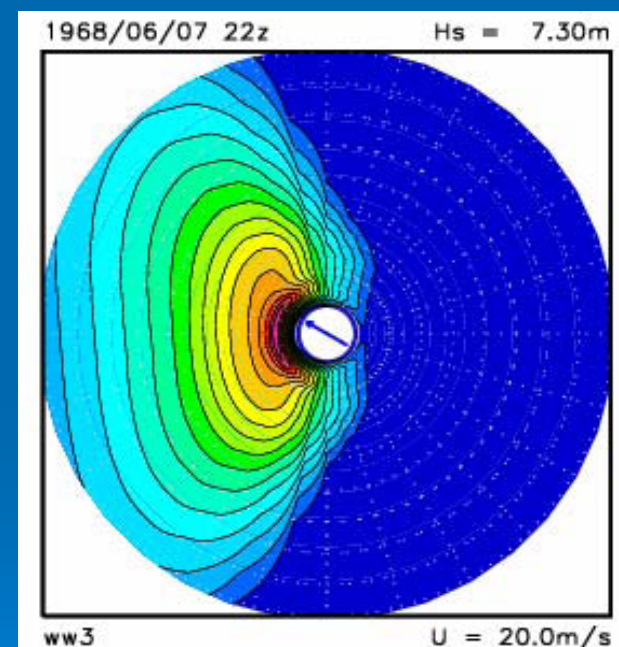
46 hr



DIA

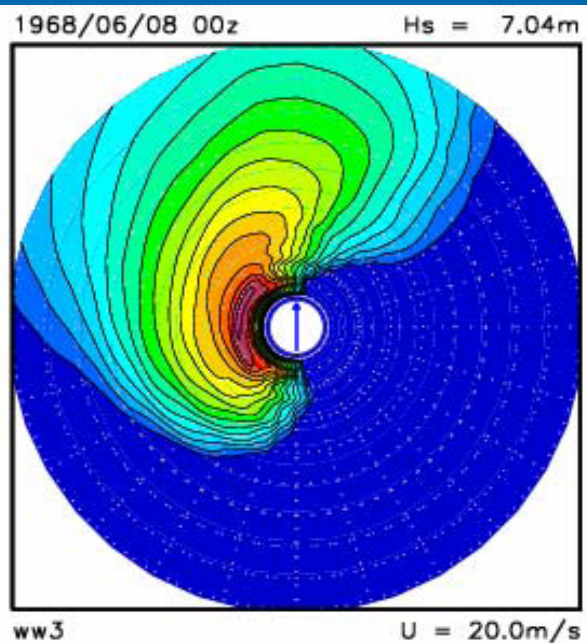


FBI

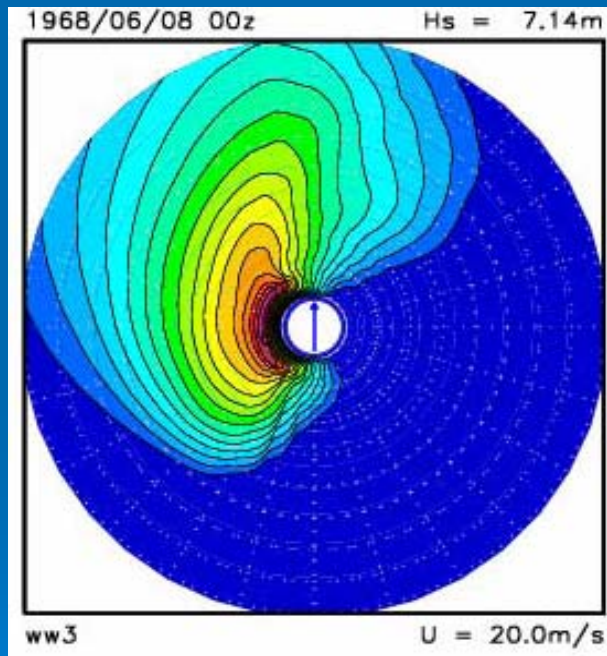


TSA

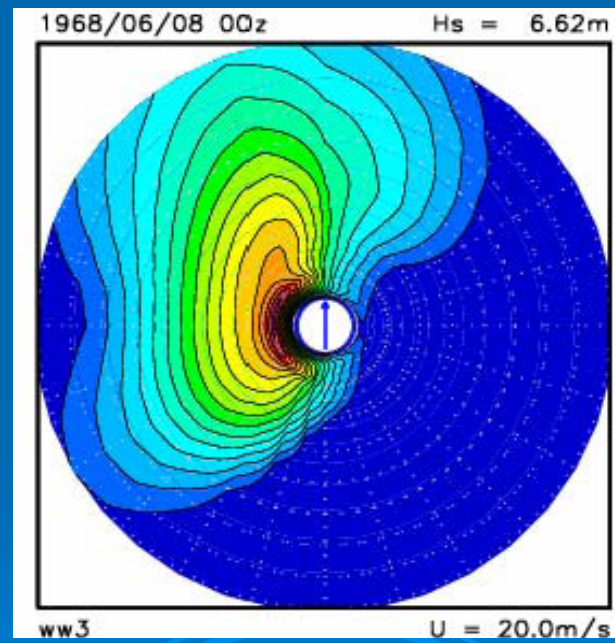
Turning winds 90°....



DIA

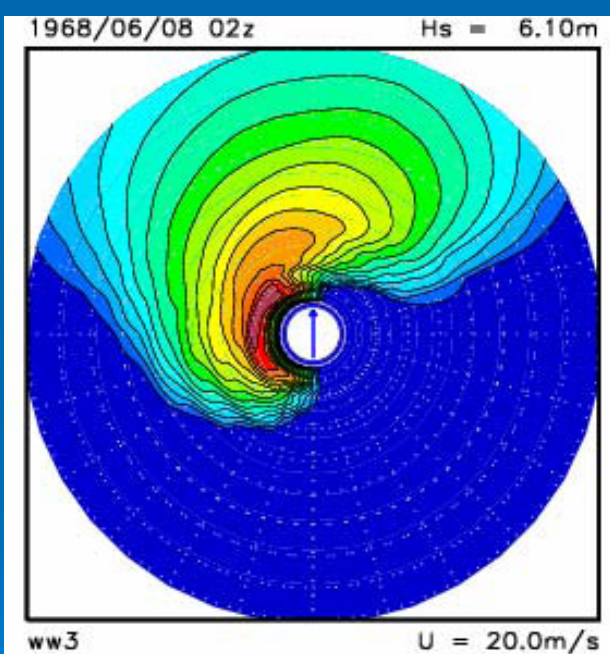


FBI

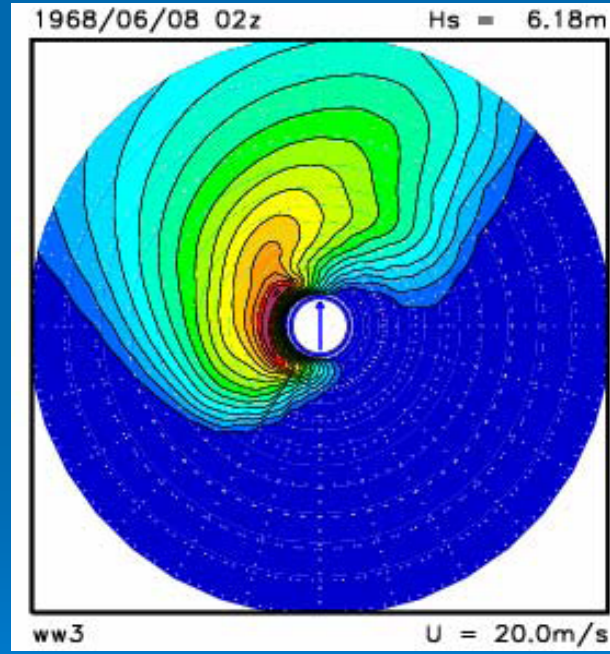


TSA

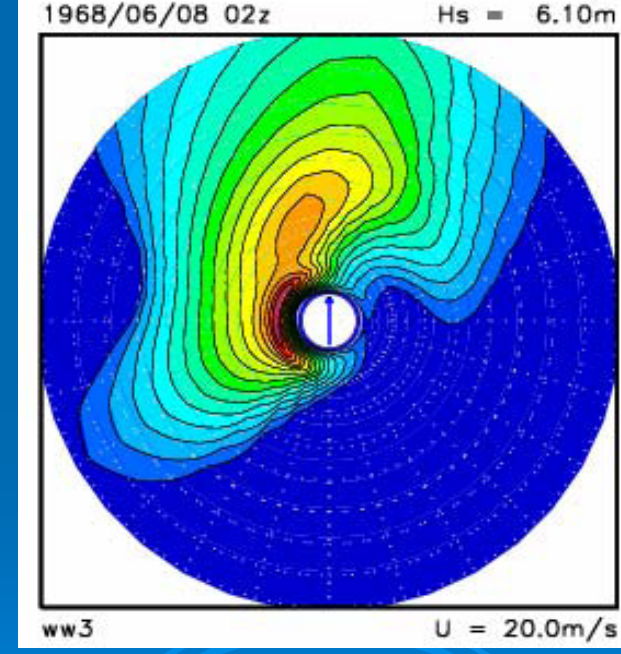
Turning winds + 2 hr



DIA

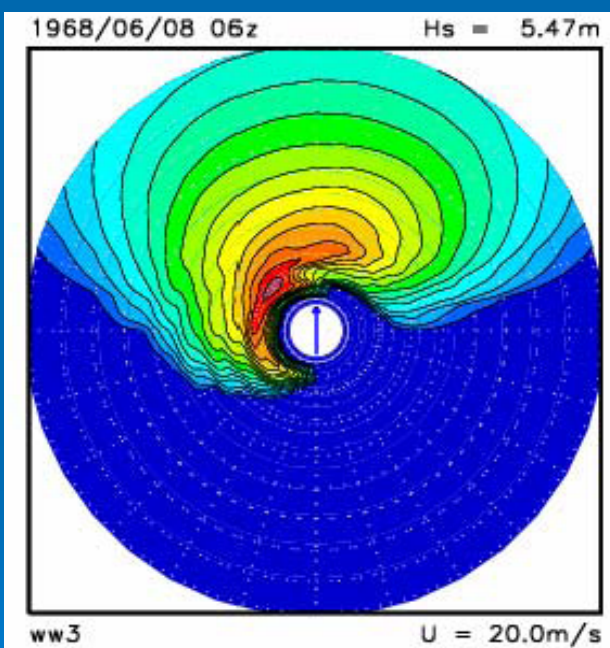


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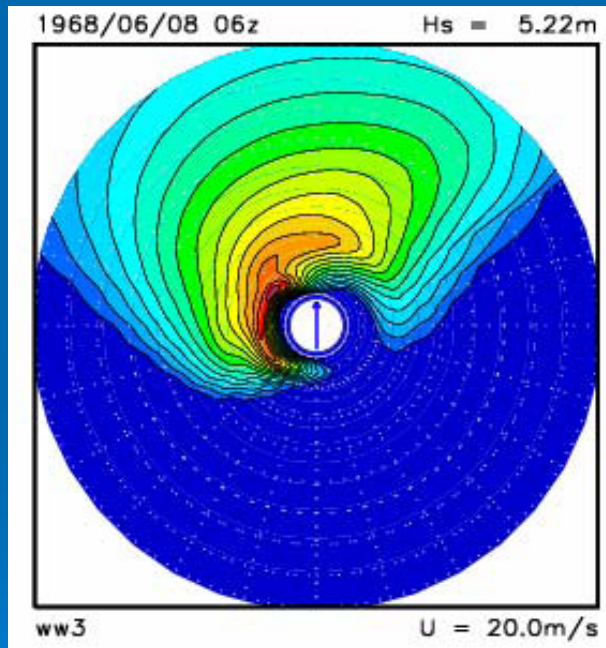


TSA

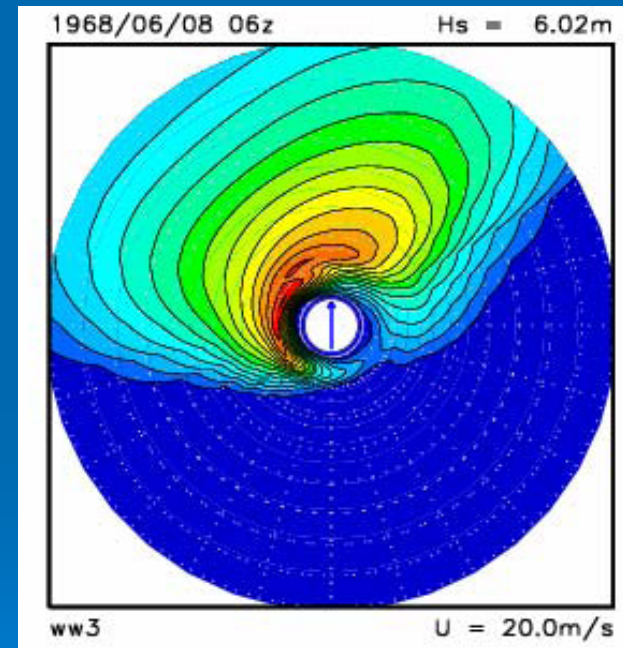
Turning winds + 6 hr



DIA

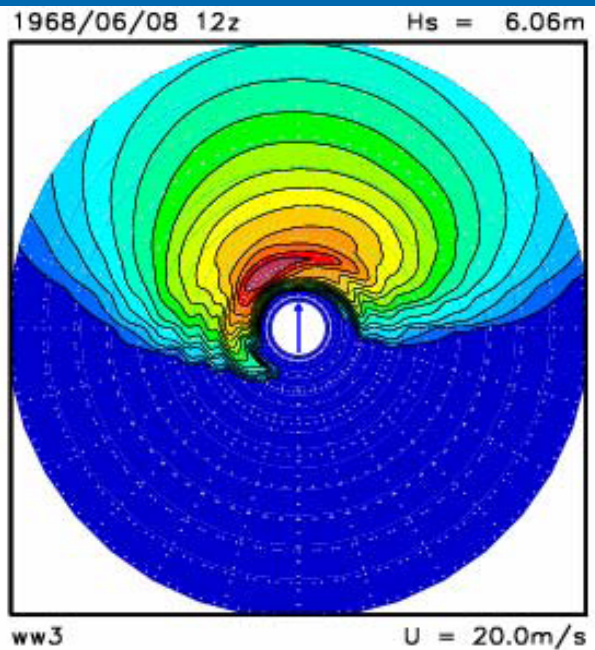


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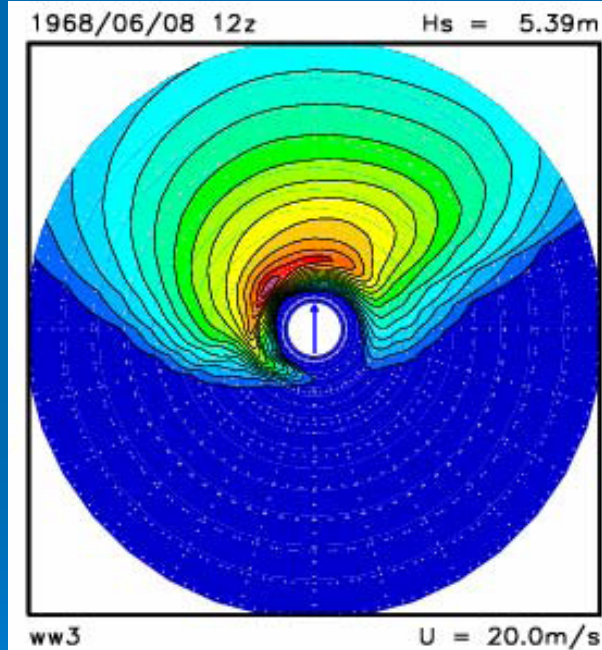


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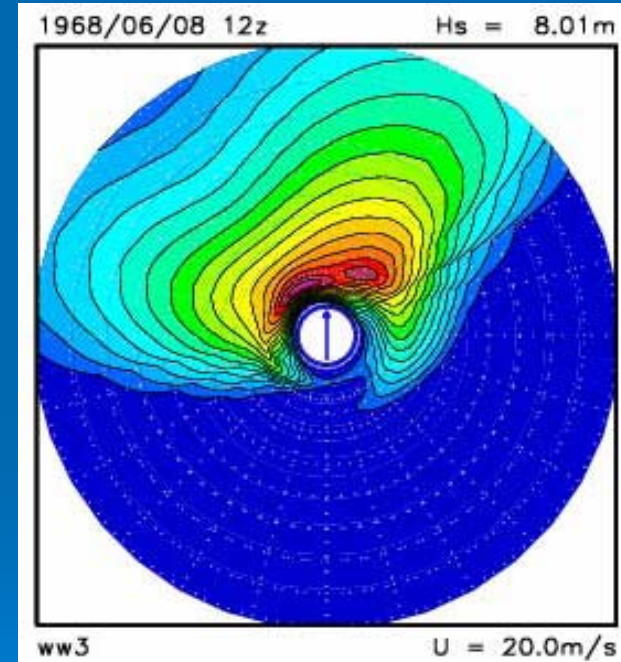
Turning winds + 12 hr



DIA

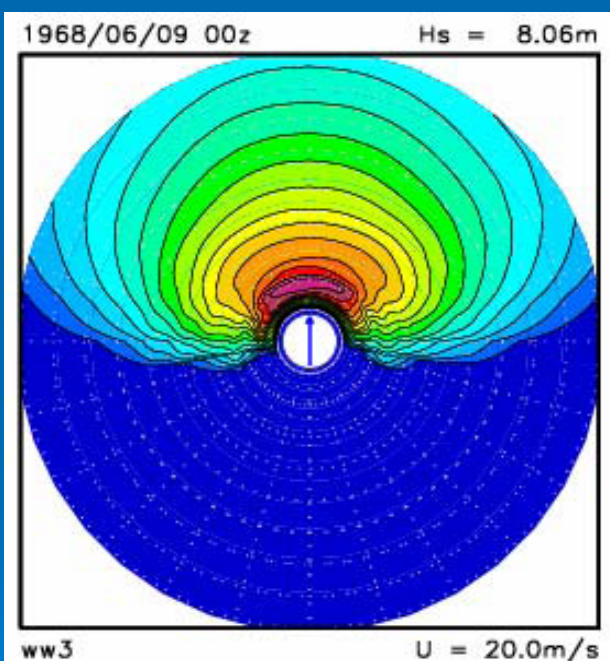


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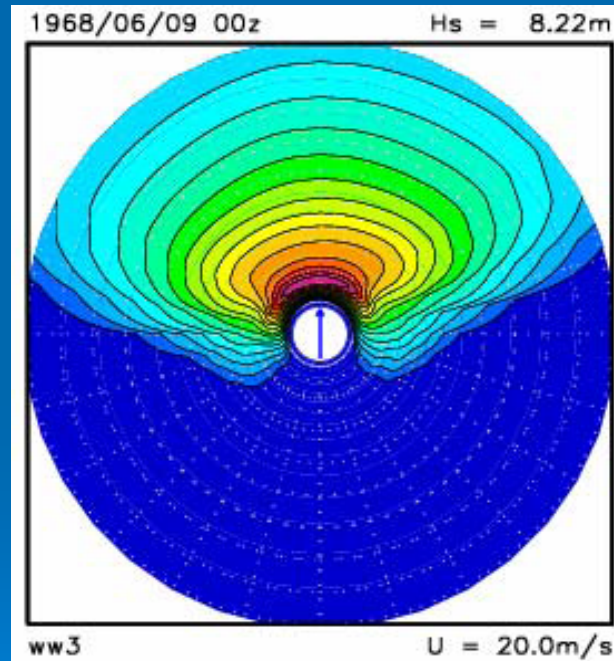


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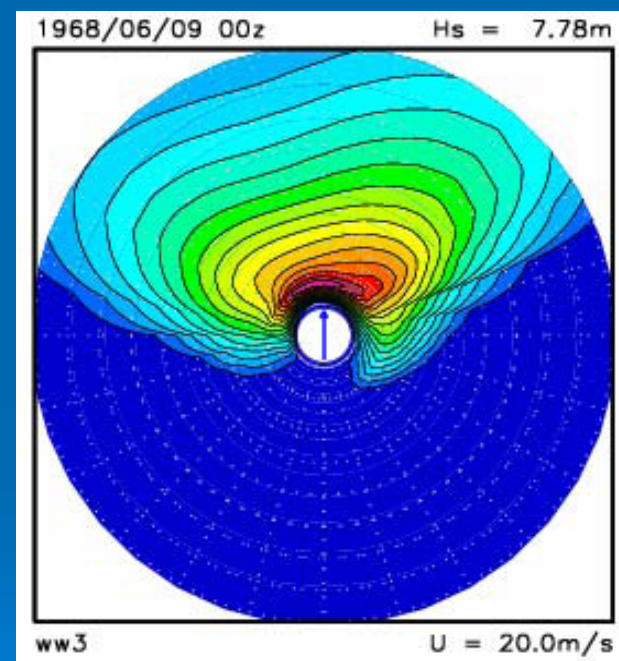
Turning winds + 24 hr



DIA

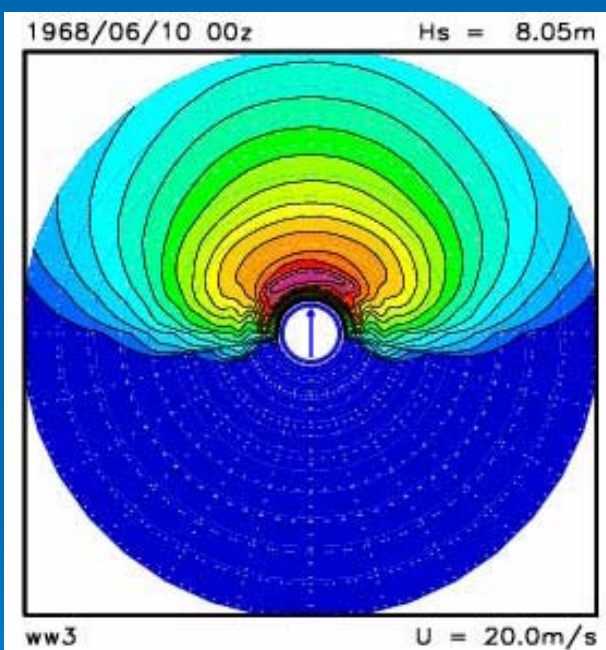


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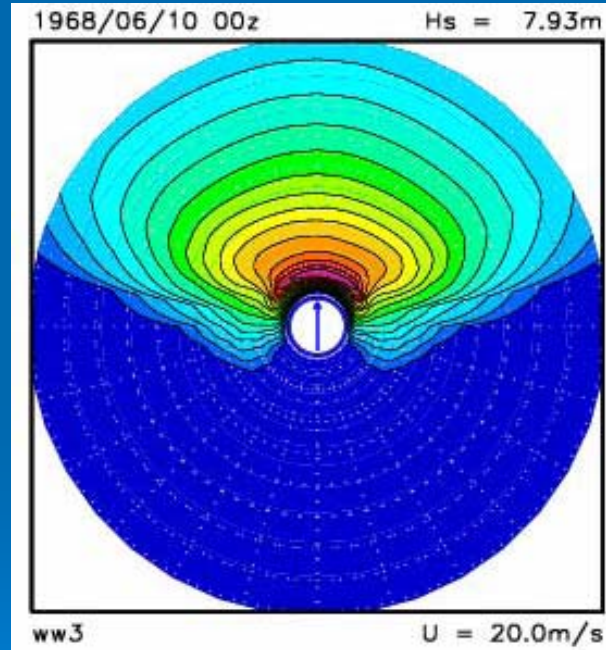


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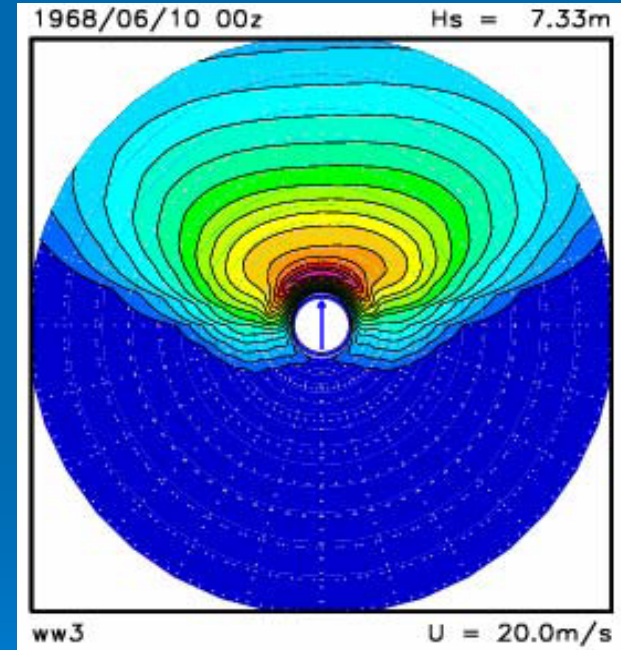
Turning winds + 48 hr



DIA



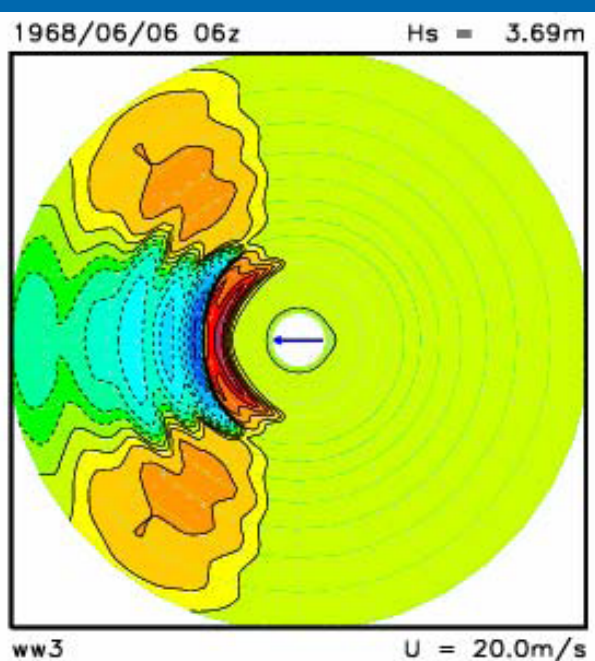
FBI



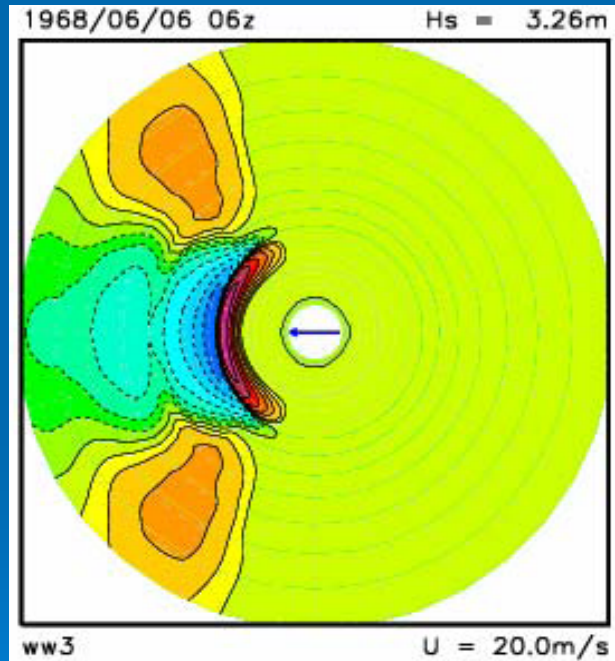
TSA

Fetch-limited wave growth

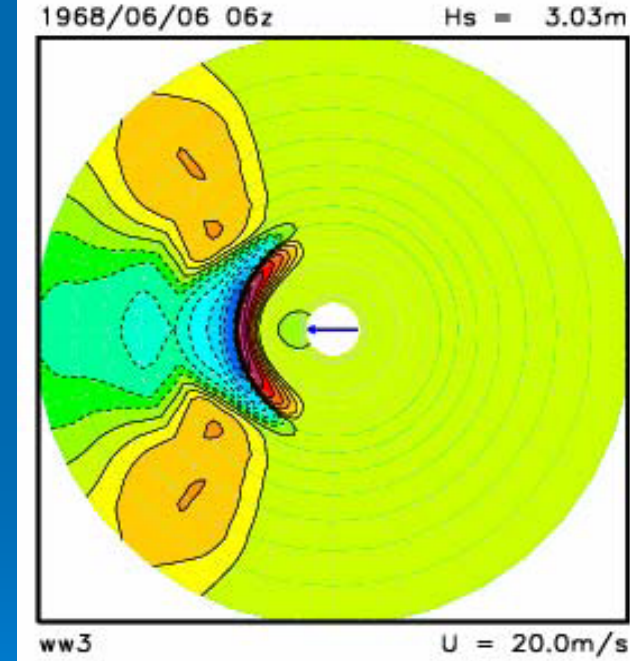
6 hr



DIA



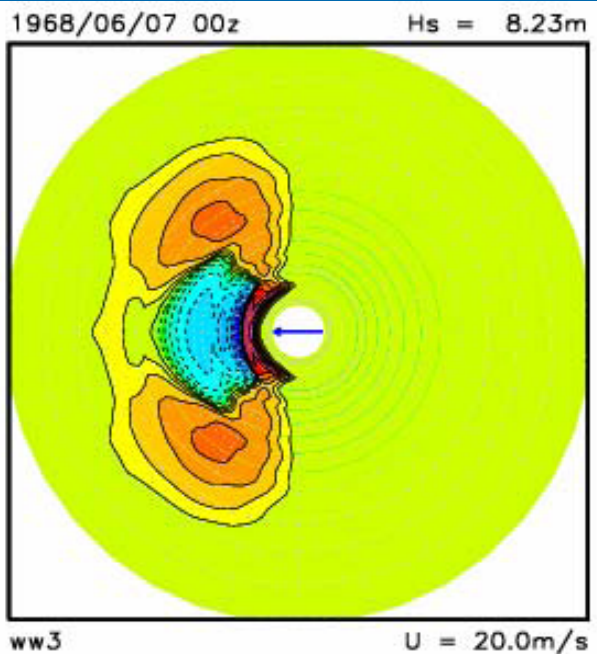
FBI



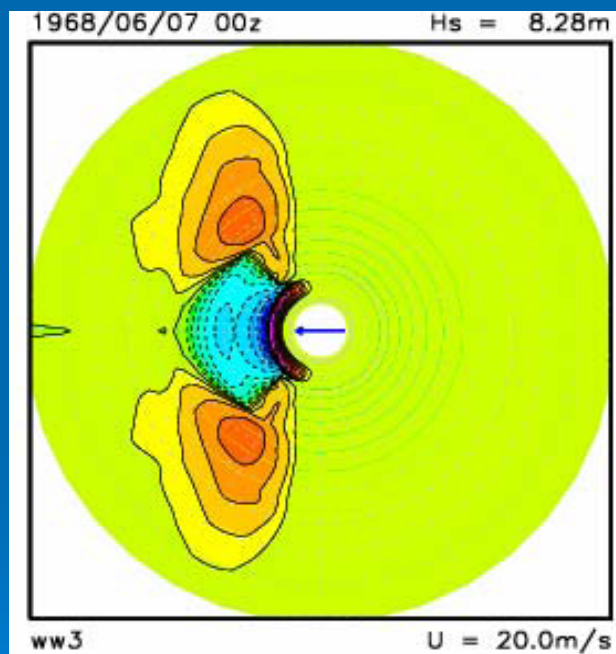
TSA

Fetch-limited wave growth

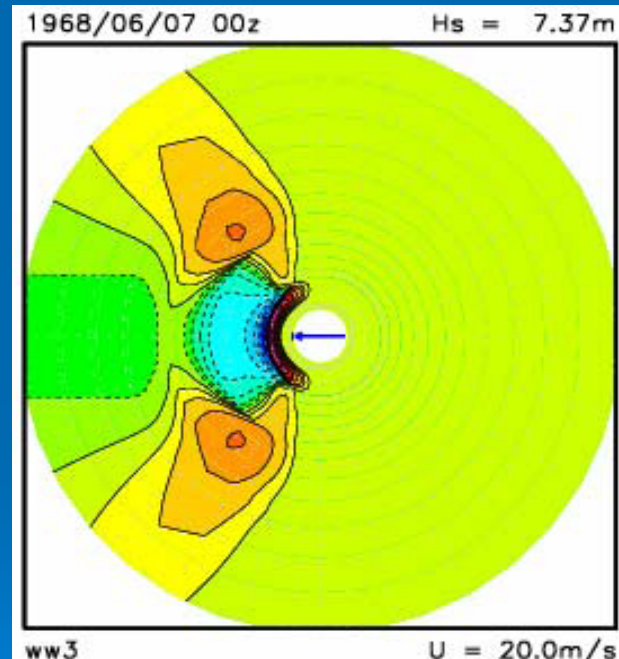
24 hr



DIA



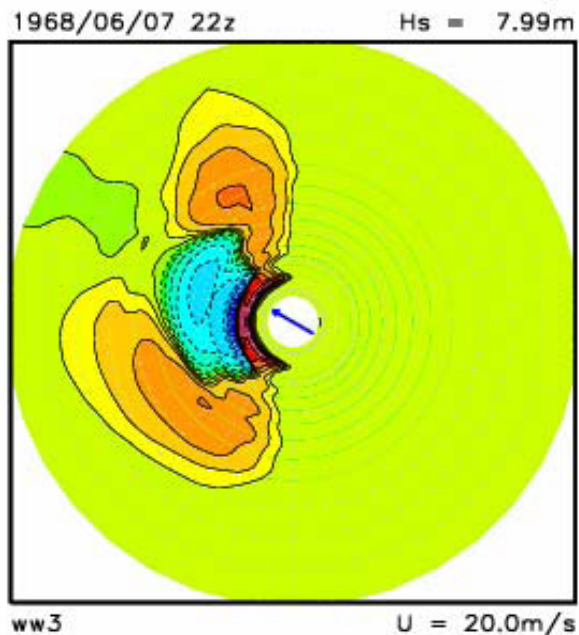
FBI



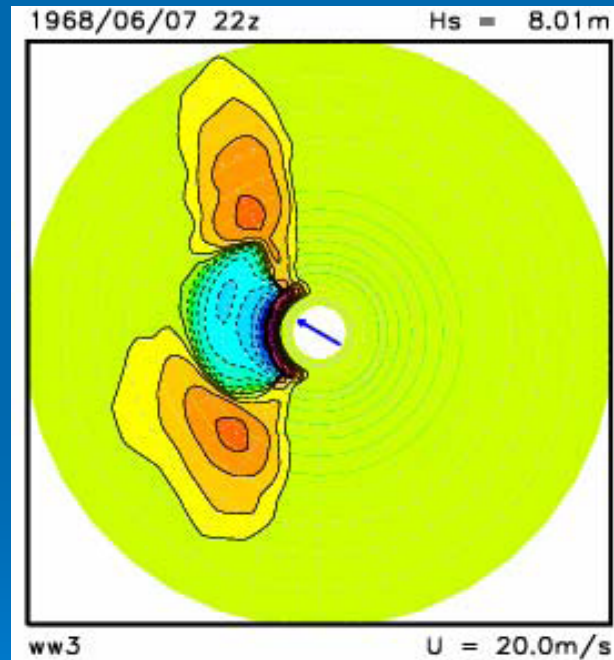
TSA

Fetch-limited wave growth

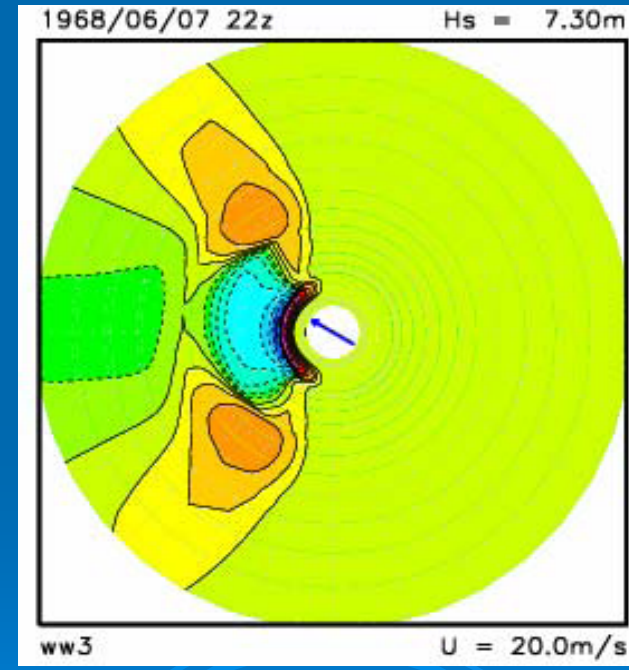
46 hr



DIA

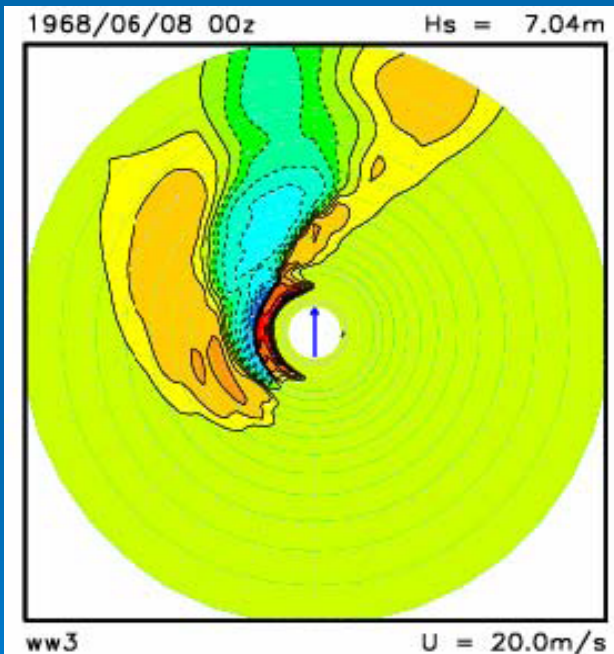


FBI

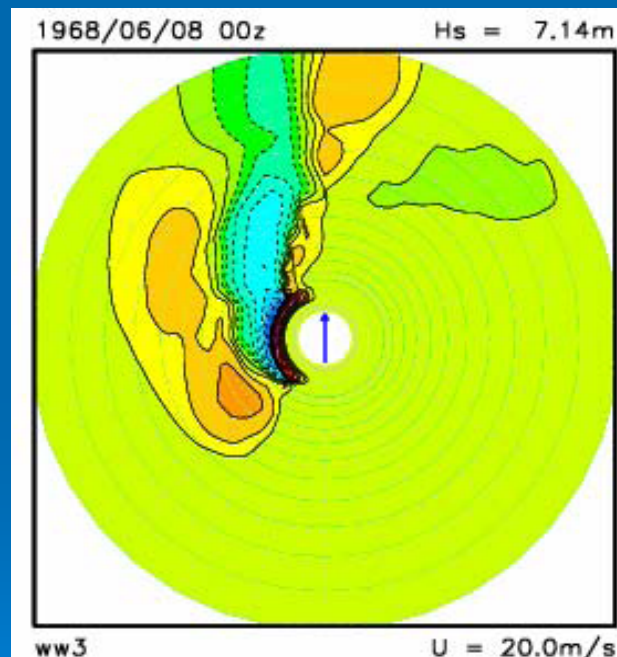


TSA

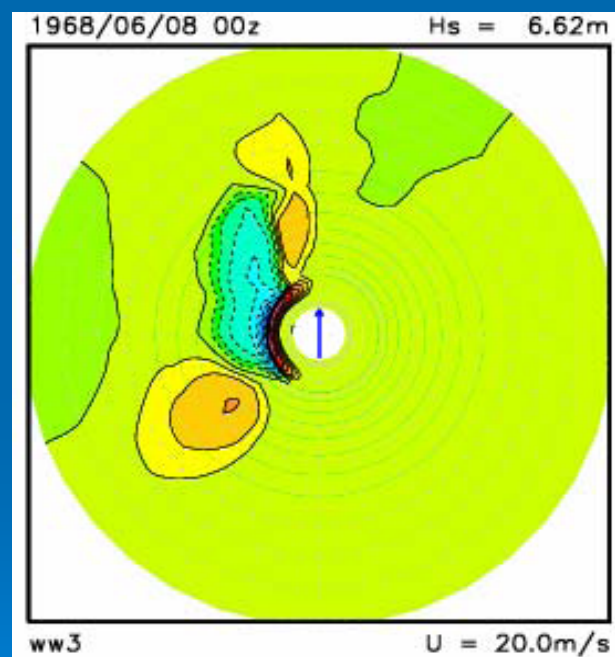
Turning winds 90°....



DIA

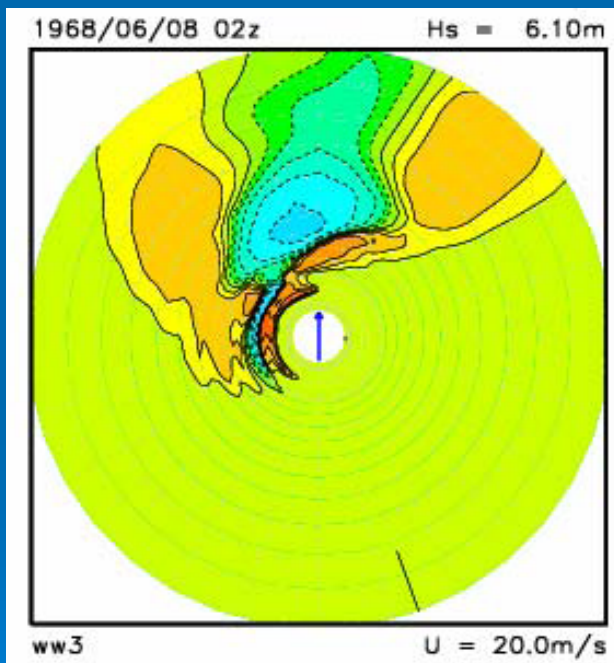


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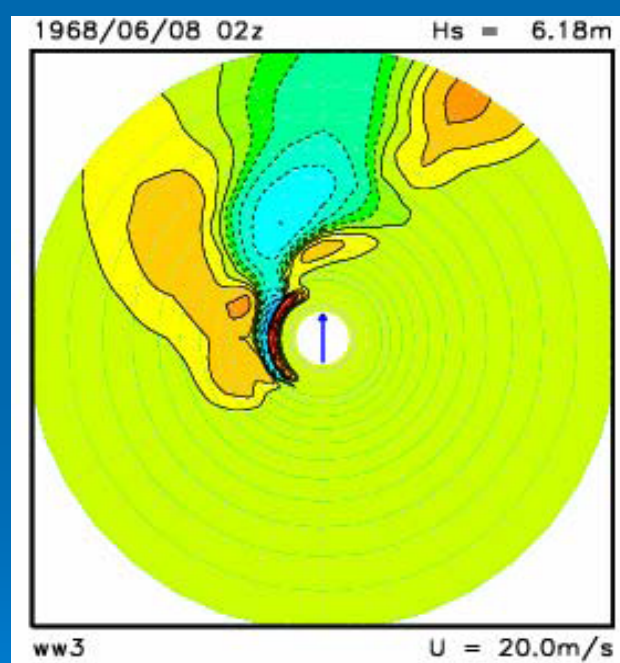


TSA

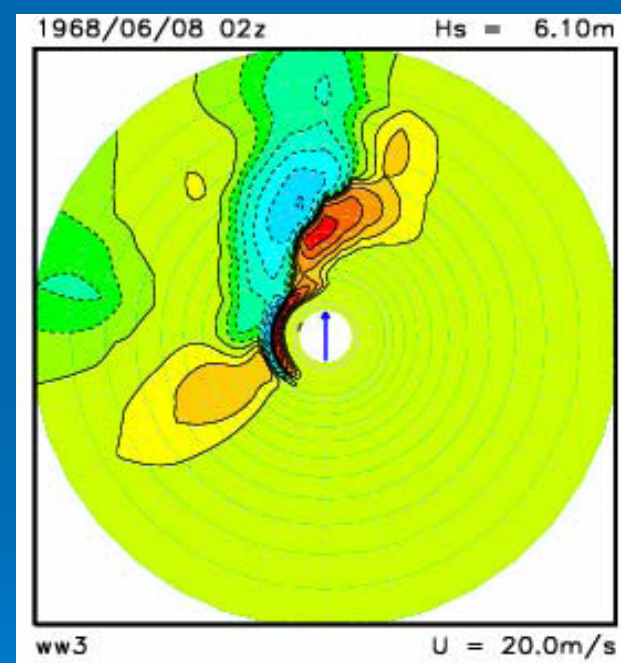
Turning winds + 2 hr



DIA

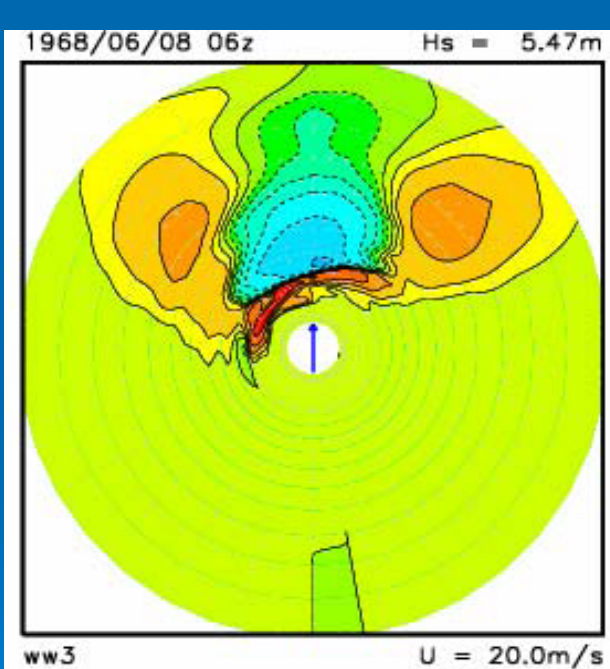


FBI

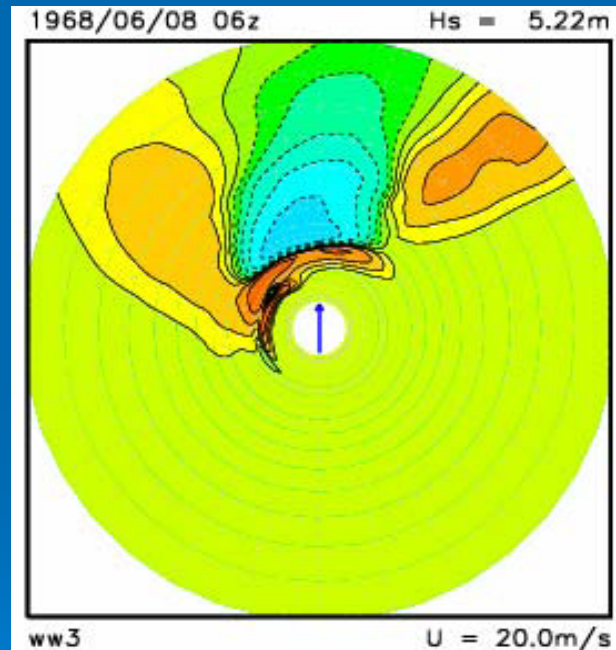


TSA

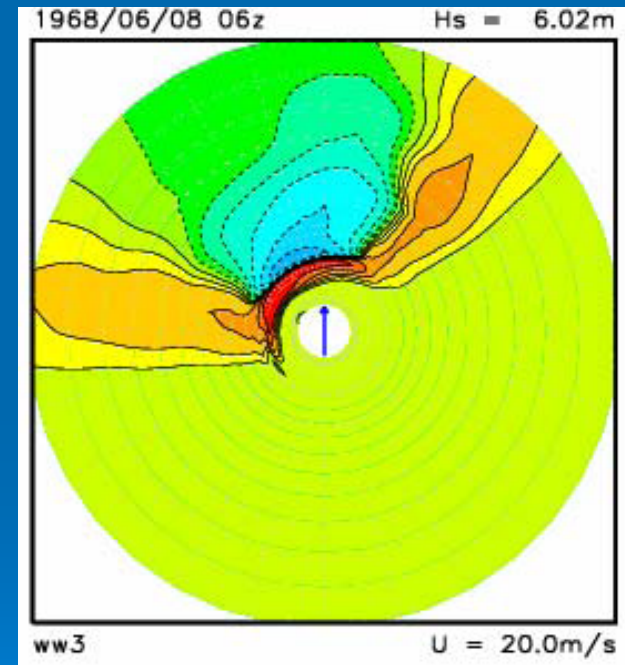
Turning winds + 6 hr



DIA

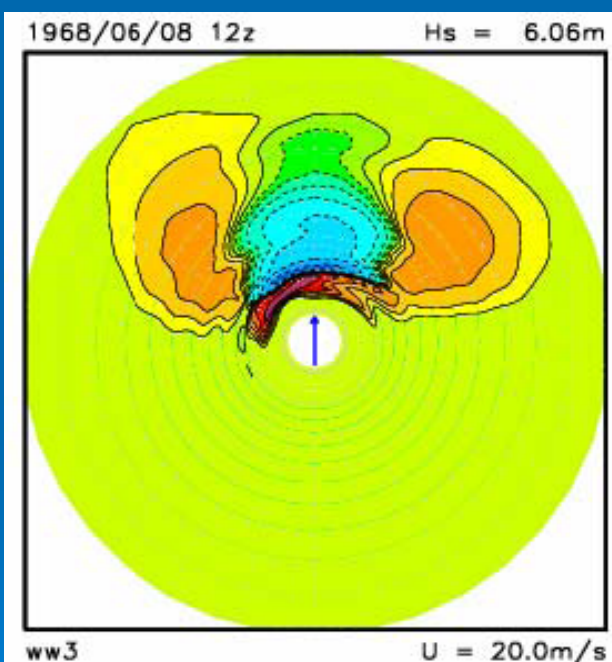


FBI

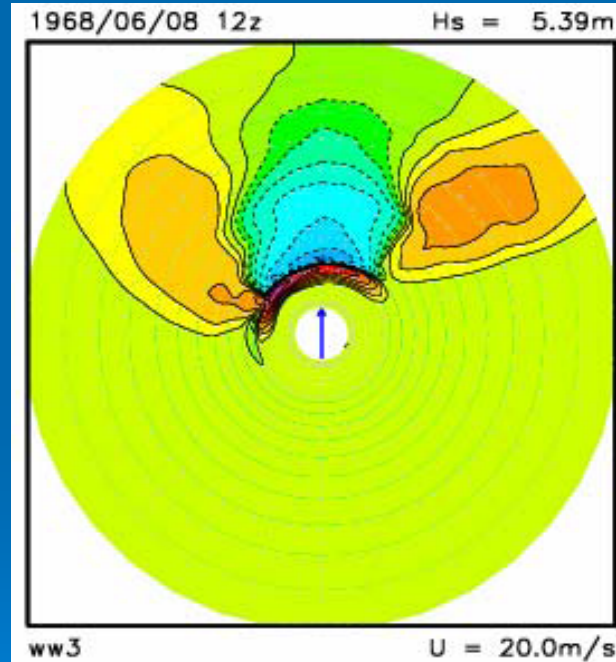


TSA

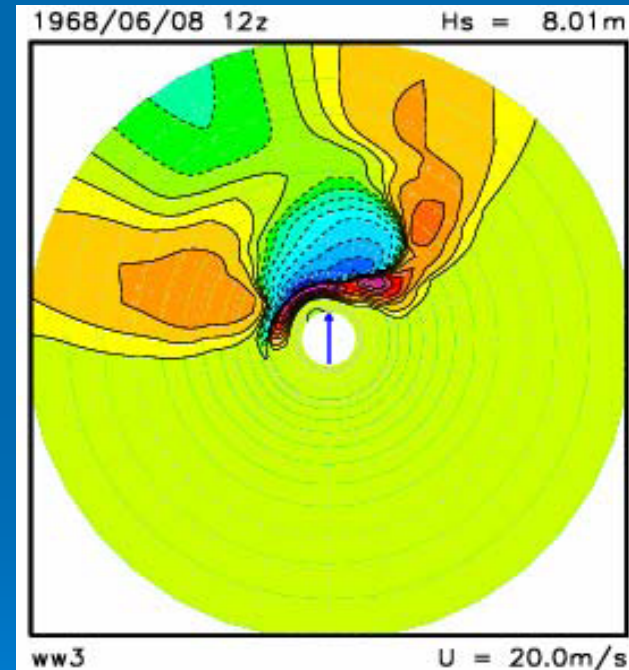
Turning winds + 12 hr



DIA

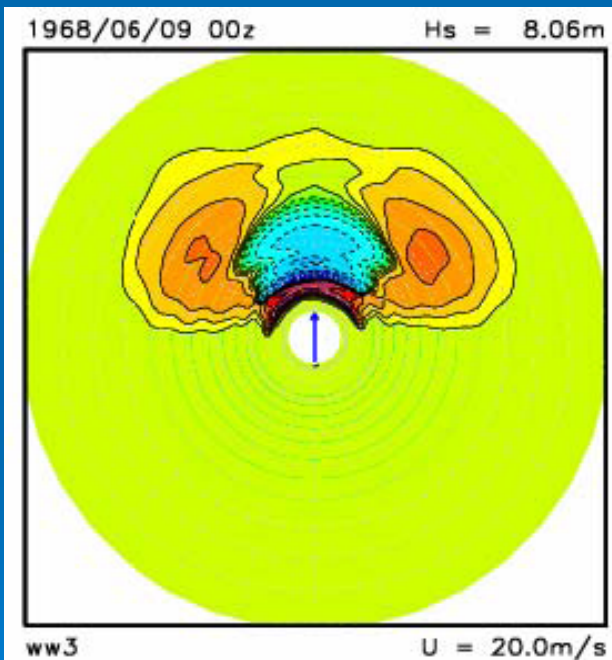


FBI

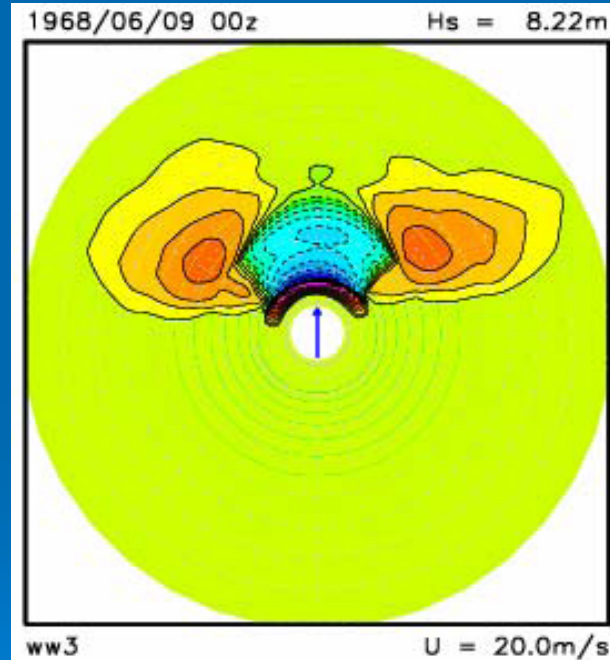


TSA

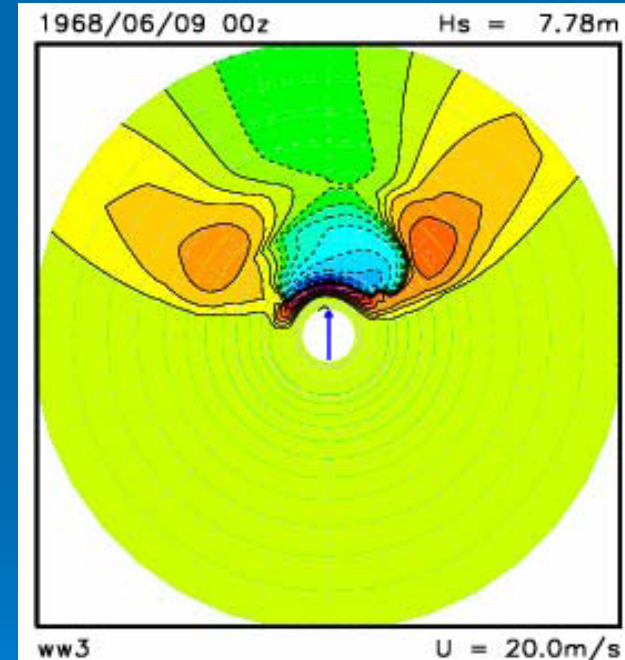
Turning winds + 24 hr



DIA

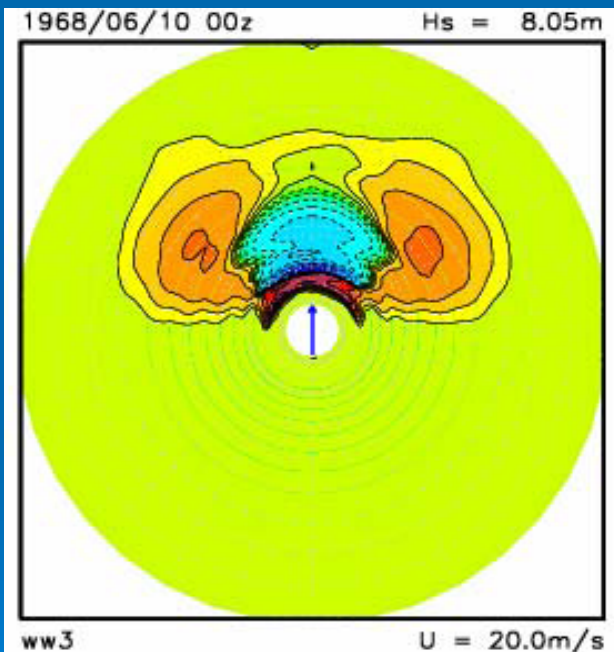


FBI

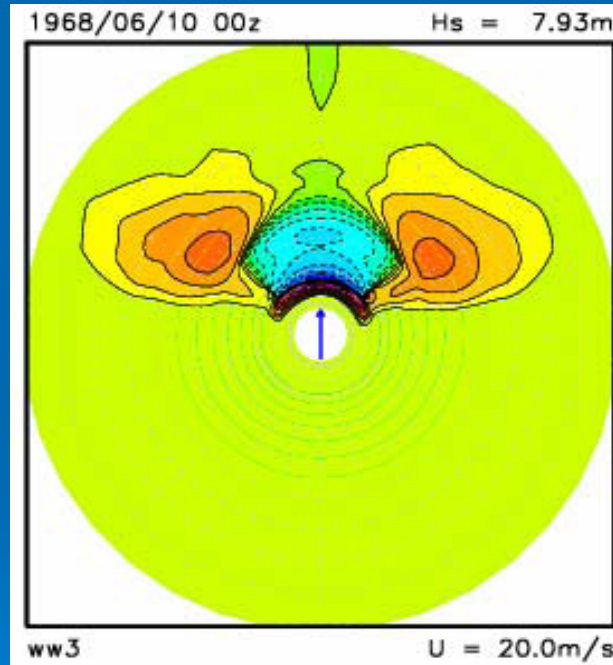


TSA

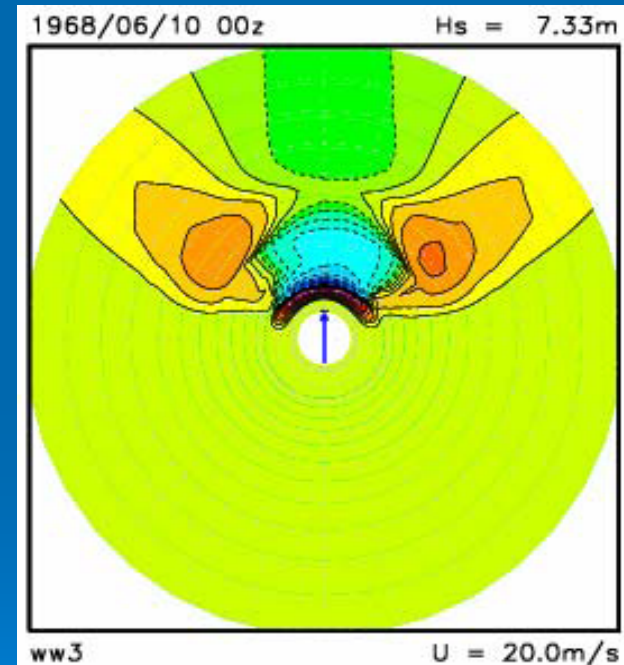
Turning winds + 48 hr



DIA

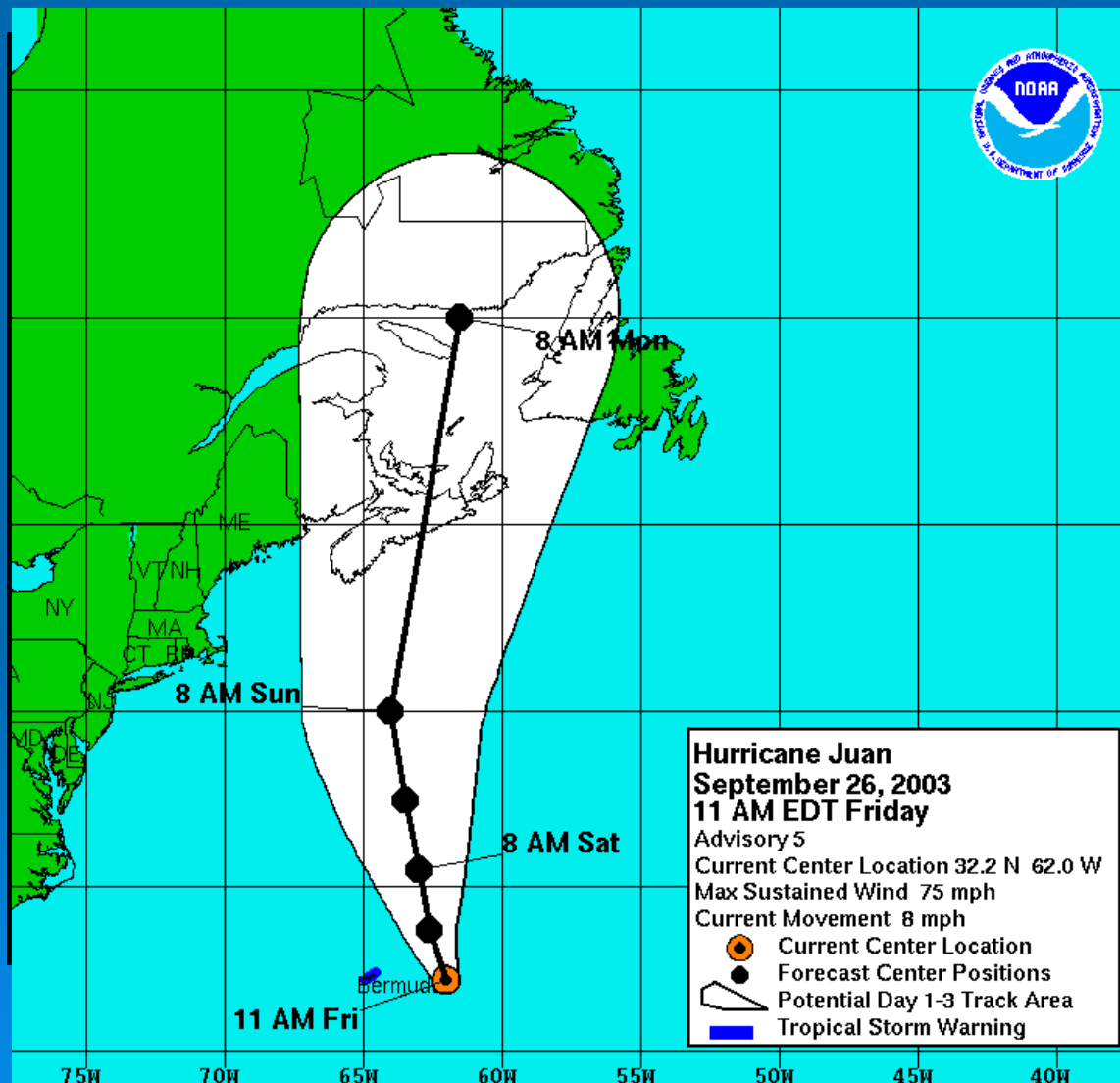


FBI

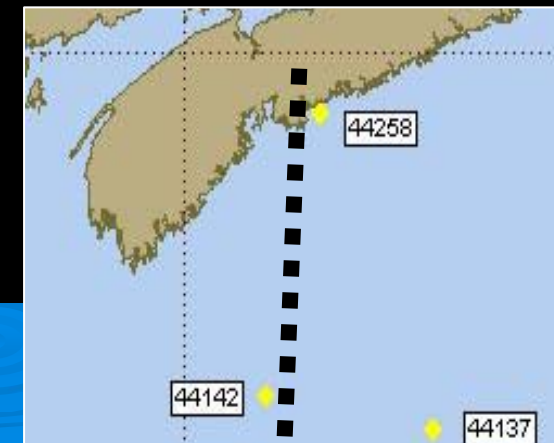


TSA

Wave Simulation during Hurricane Juan (2003)



Track at max. wind radius
(0m...)
2-3 AM UTC 29 Sept.
SL



Wave model simulation duration:

03 UTC Sept. 27 to 09 UTC Sept. 29 (55 hours)

Wind fields:

For 3 outer domains: 6-hourly COAMPS winds

- corrected by observed winds
- cyclone data, methodology (Xu et al. 2007; Perrie et al., 2009)

For Halifax Harbour domain: observed hourly winds at 44258 station are applied as input fields to wave models,

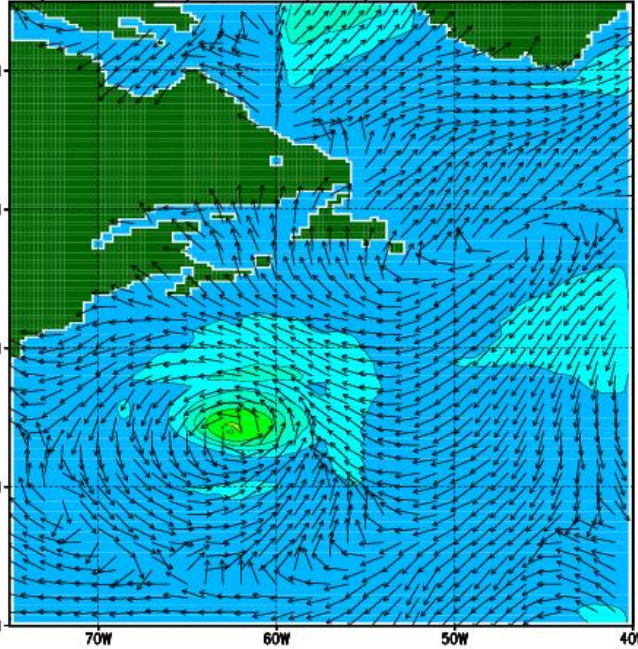
Hurricane Juan

DIA

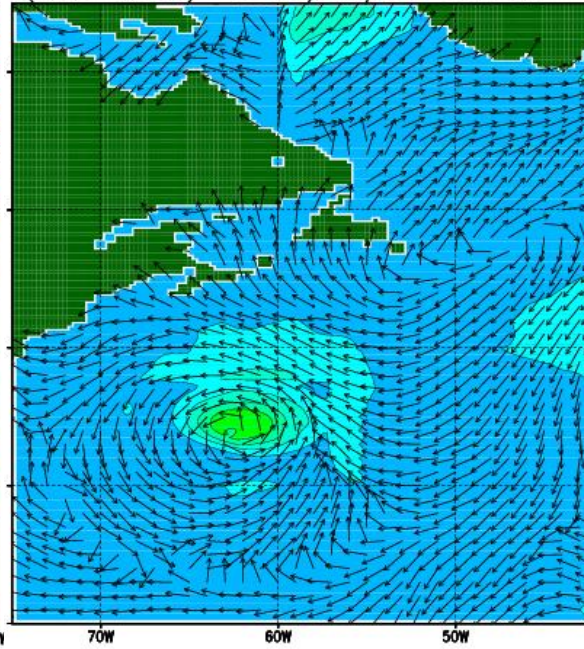
FBI

TSA

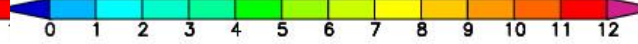
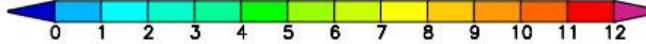
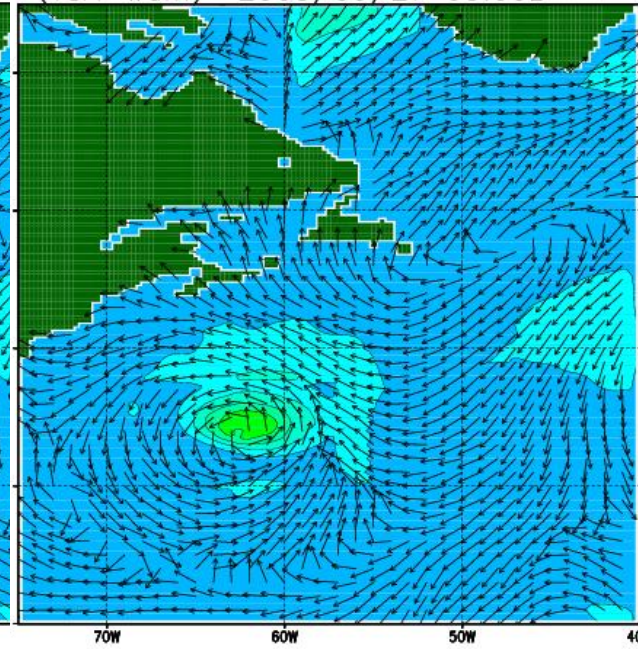
(DIA-wam) 2003/09/27 05:00z



(WRT-wam) 2003/09/27 05:00z



(TSA-wam) 2003/09/27 05:00z

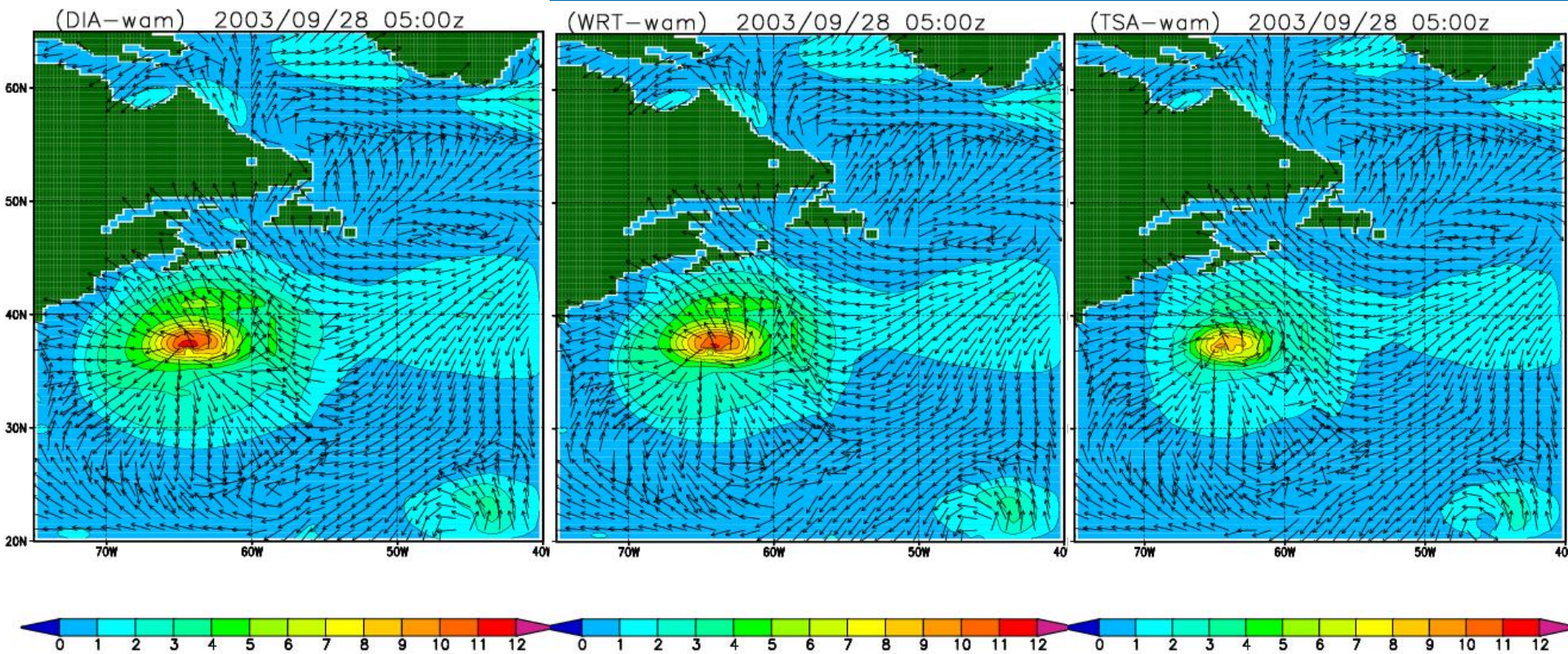


Hurricane Juan

DIA

FBI

TSA



Hurricane Juan

DIA

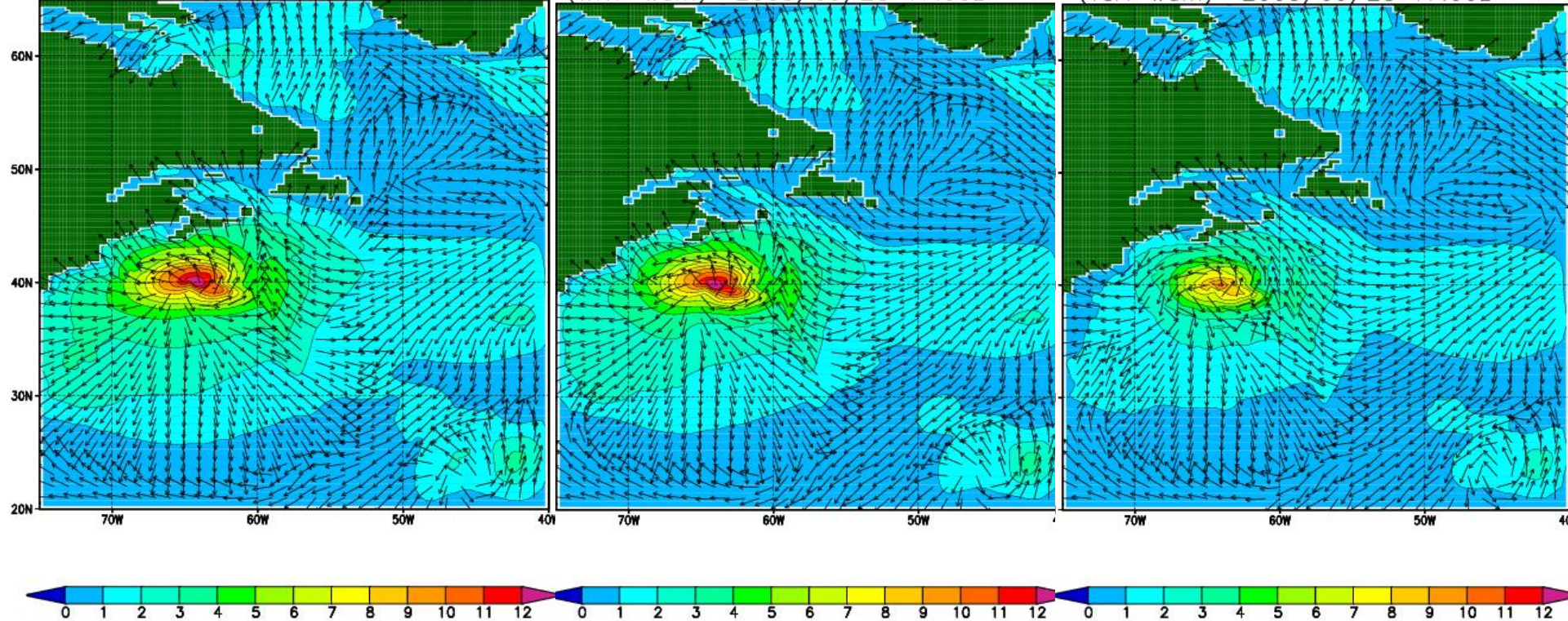
FBI

TSA

(DIA-wam) 2003/09/28 17:00z

(WRT-wam) 2003/09/28 17:00z

(TSA-wam) 2003/09/28 17:00z



Hurricane Juan

DIA

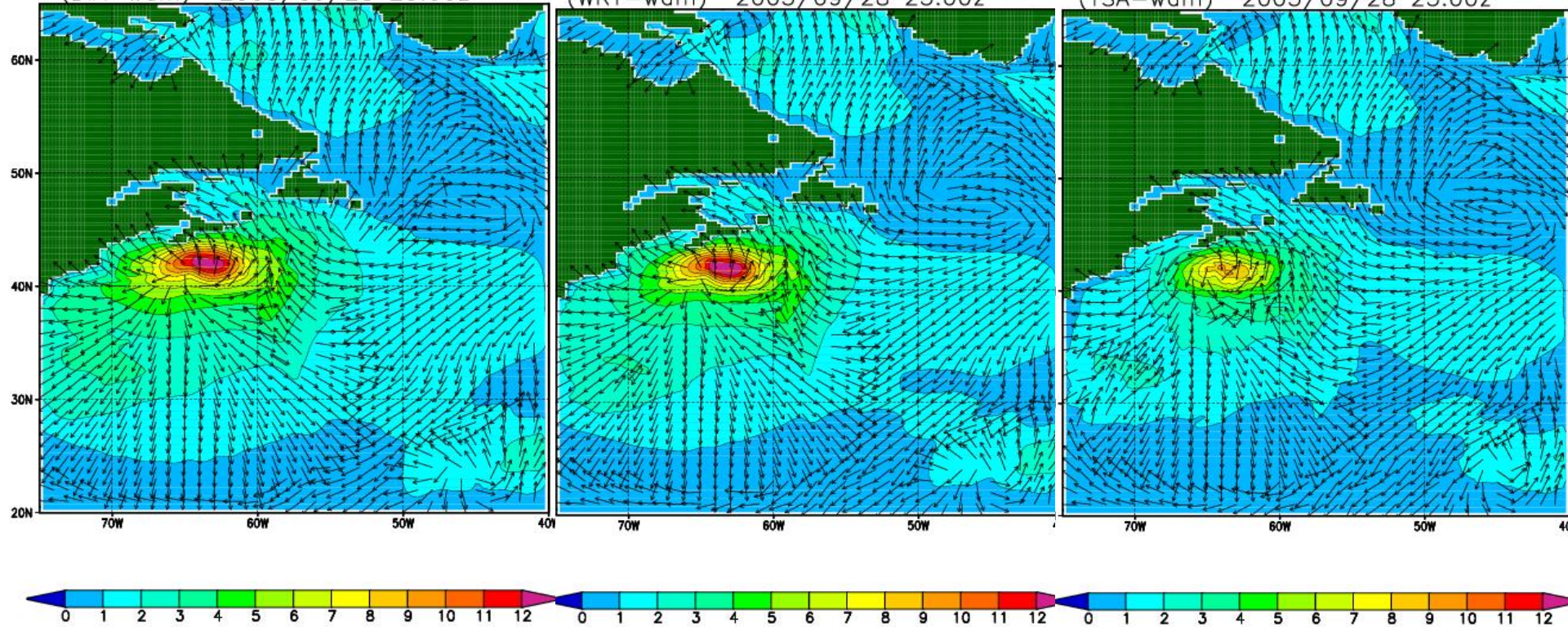
FBI

TSA

(DIA-wam) 2003/09/28 23:00z

(WRT-wam) 2003/09/28 23:00z

(TSA-wam) 2003/09/28 23:00z



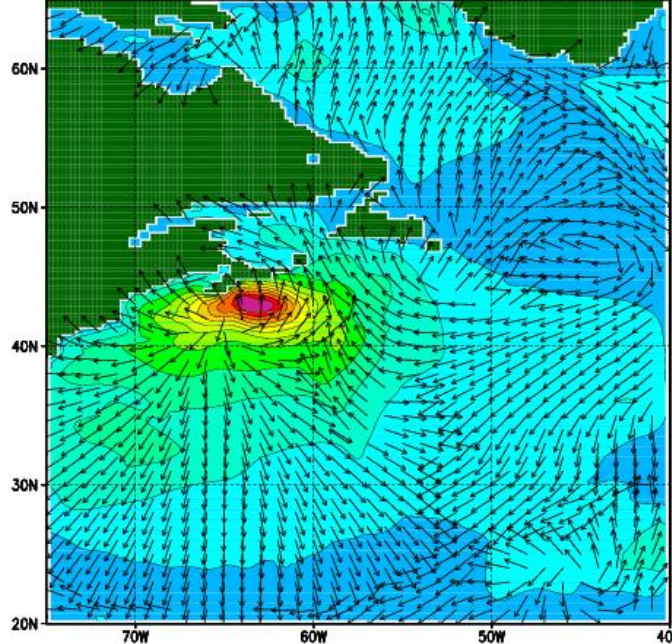
Hurricane Juan

DIA

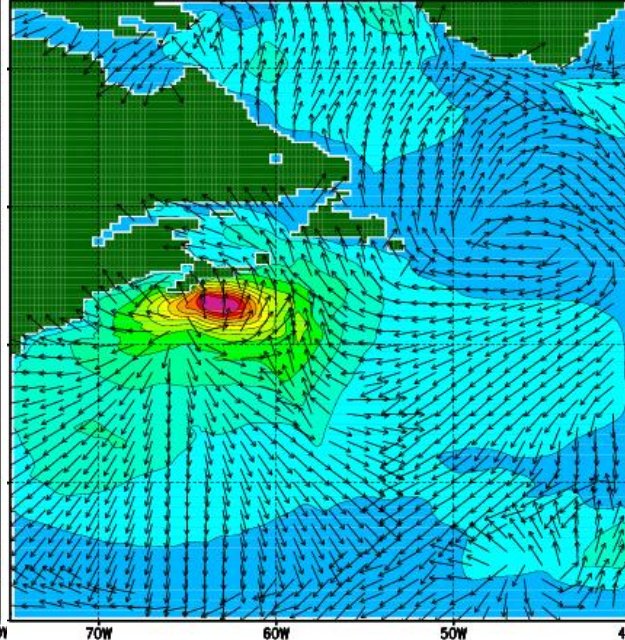
FBI

TSA

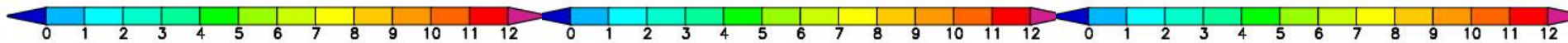
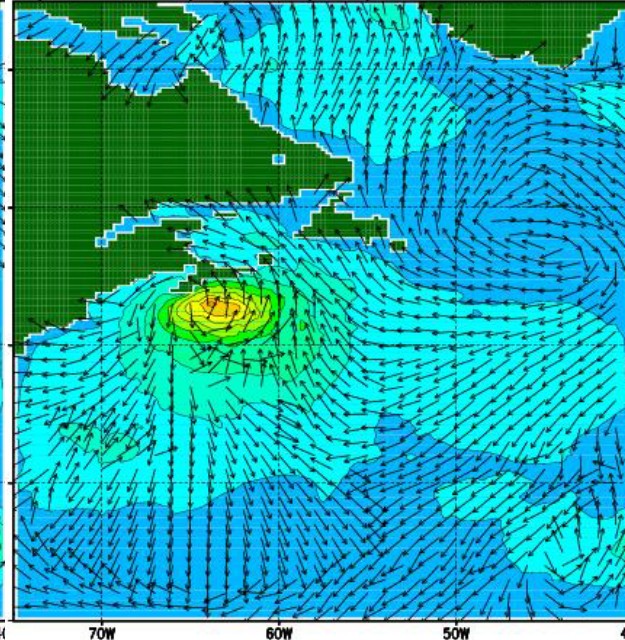
(DIA-wam) 2003/09/29 01:00z



(WRT-wam) 2003/09/29 01:00z



(TSA-wam) 2003/09/29 01:00z



Hurricane Juan

DIA

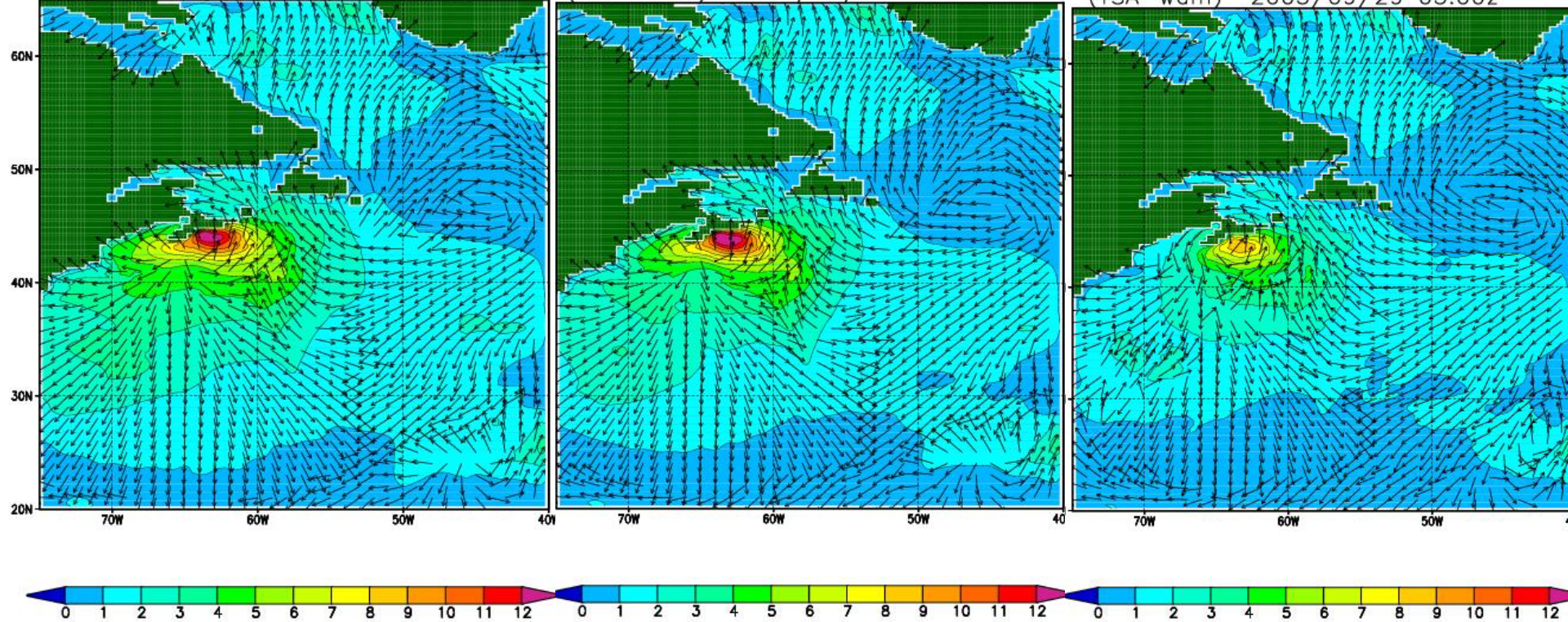
FBI

TSA

(DIA-wam) 2003/09/29 03:00z

(WRT-wam) 2003/09/29 03:00z

(TSA-wam) 2003/09/29 03:00z



Hurricane Juan

DIA

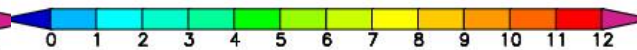
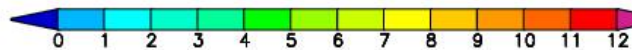
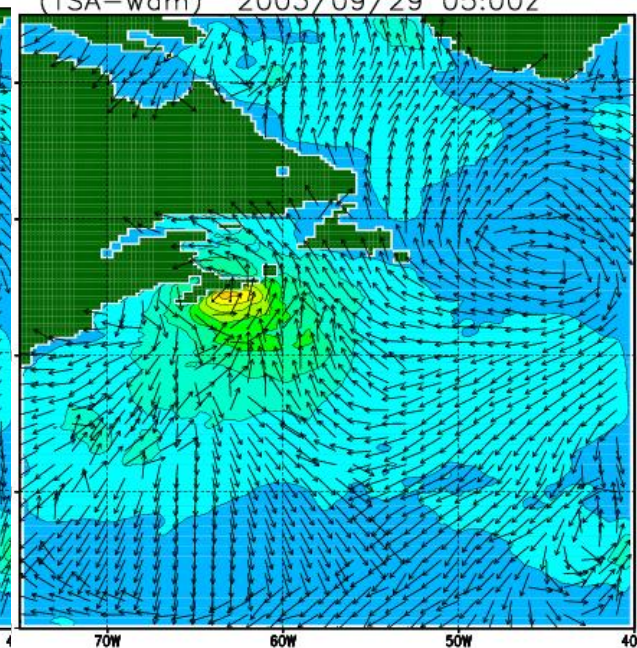
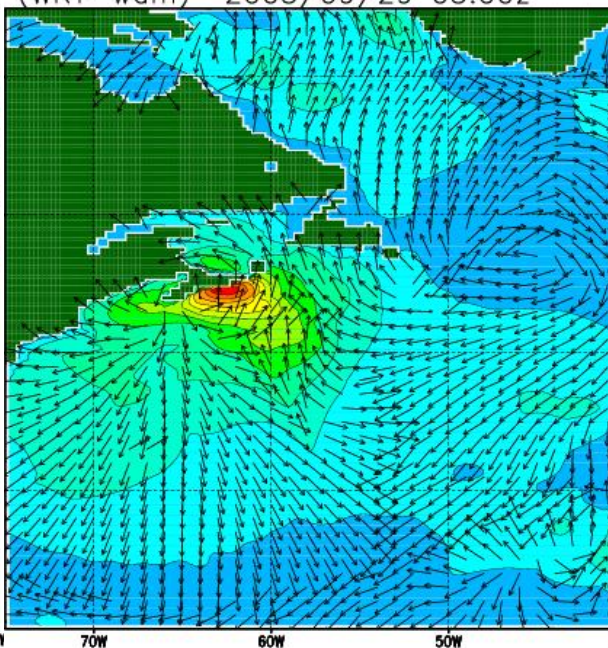
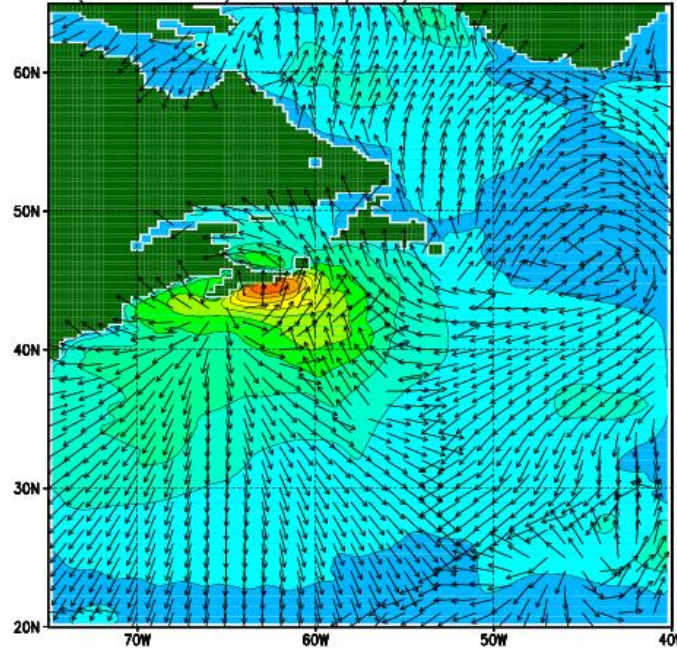
FBI

TSA

(DIA-wam) 2003/09/29 05:00z

(WRT-wam) 2003/09/29 05:00z

(TSA-wam) 2003/09/29 05:00z



Hurricane Juan

DIA

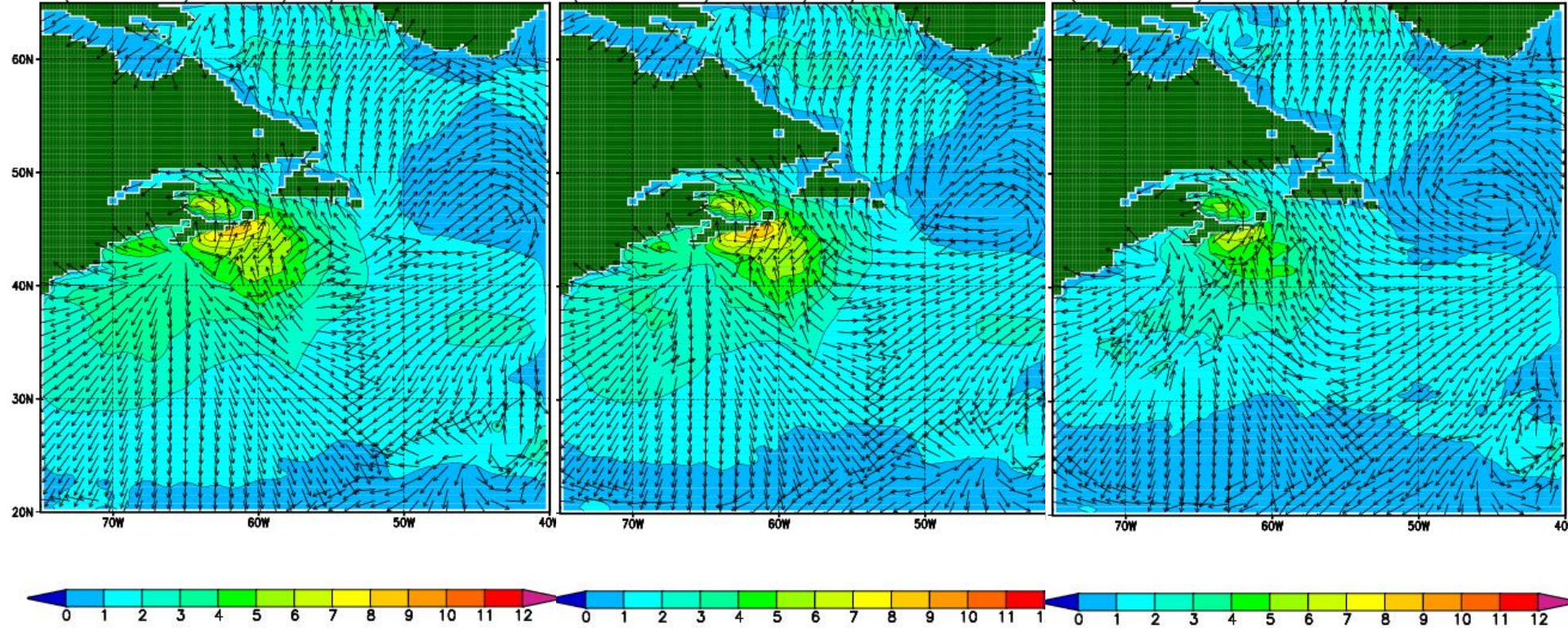
FBI

TSA

(DIA-wam) 2003/09/29 07:00z

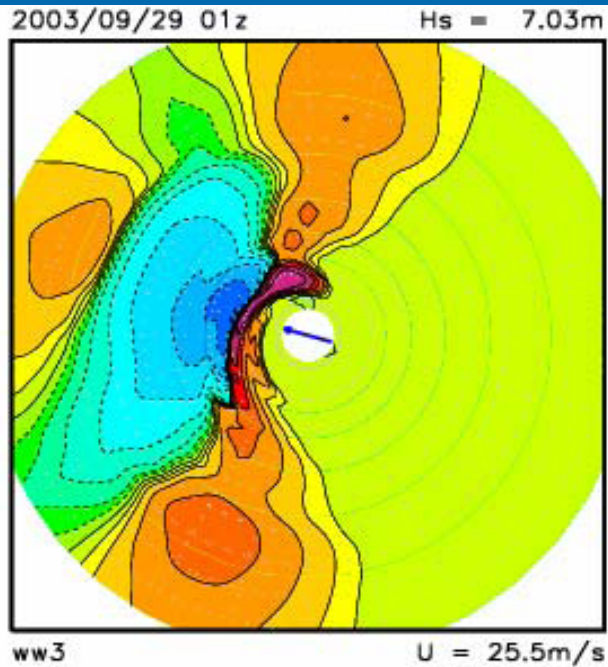
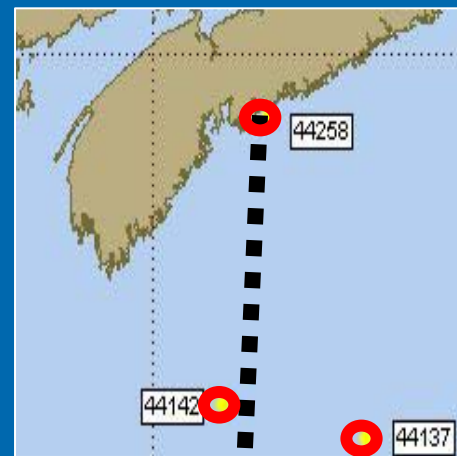
(WRT-wam) 2003/09/29 07:00z

(TSA-wam) 2003/09/29 07:00z

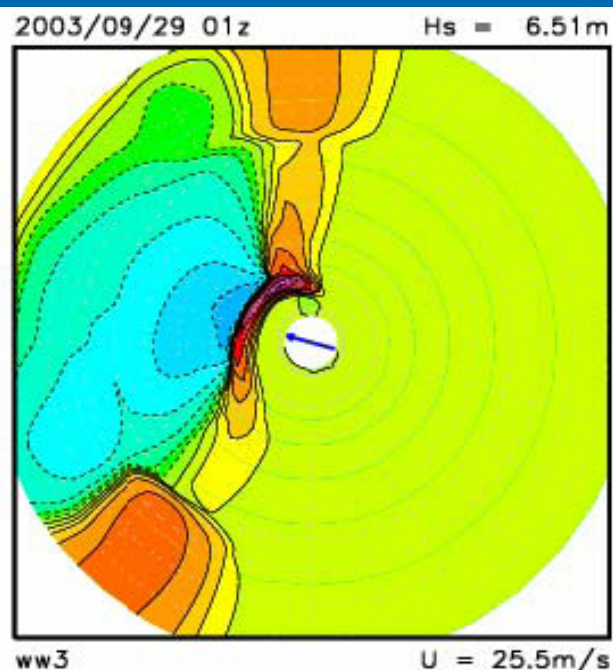


01UTC Sept 29 2003

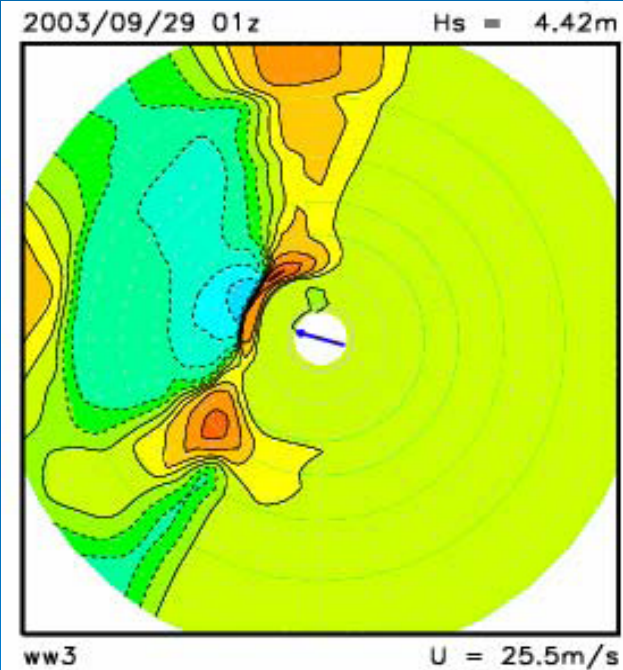
Snl



DIA



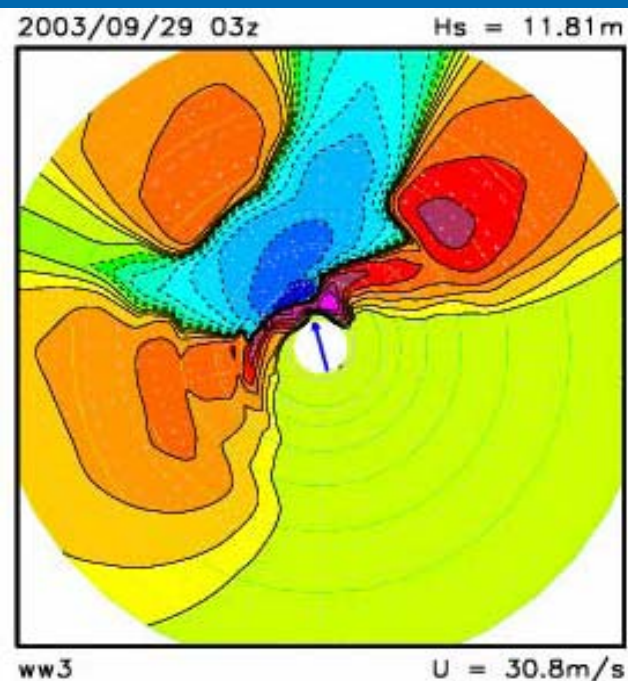
FBI



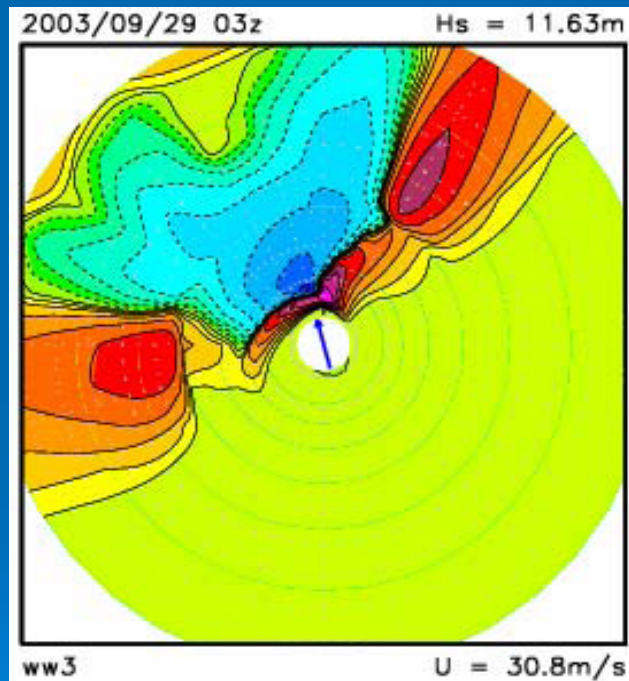
TSA

03UTC Sept 29 2003

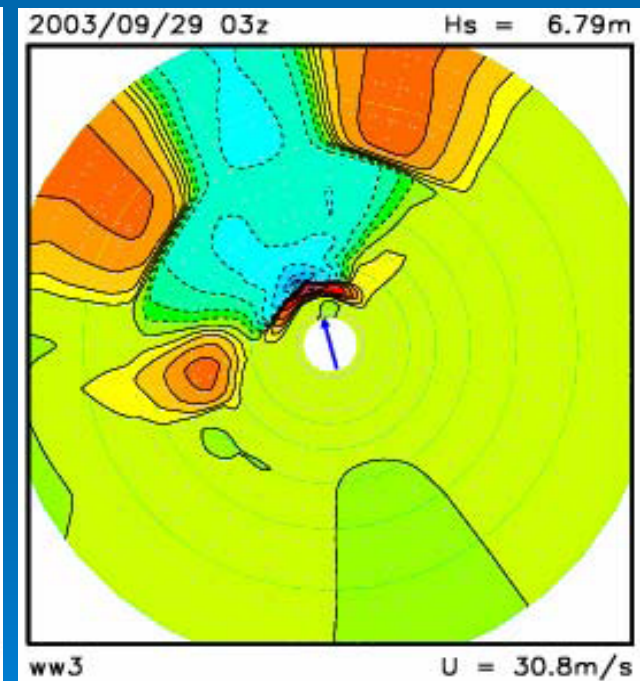
Snl



DIA



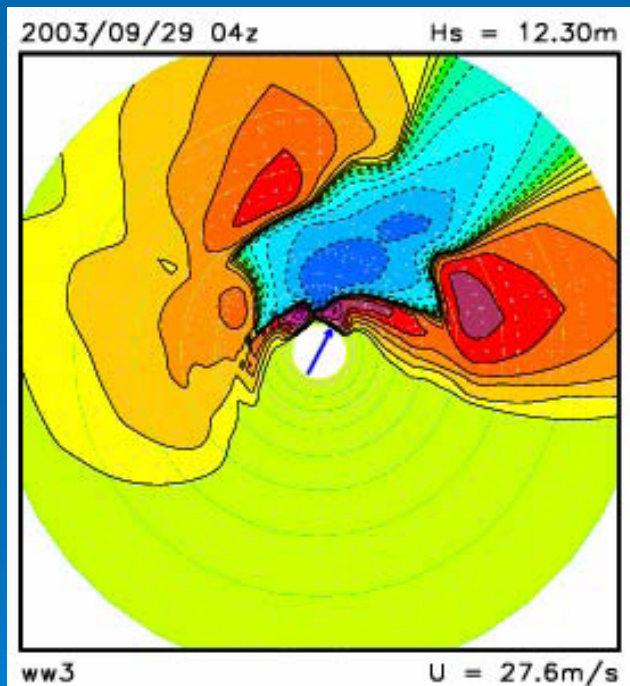
FBI



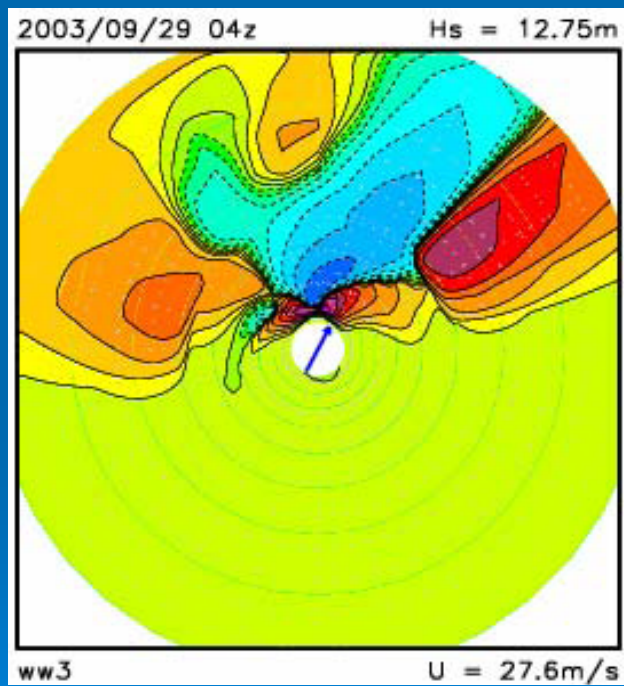
TSA

04UTC Sept 29 2003

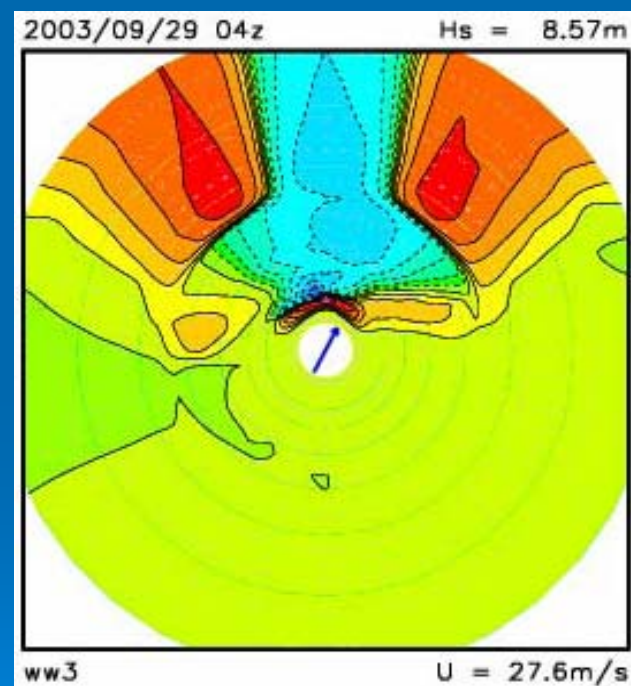
SnI



DIA



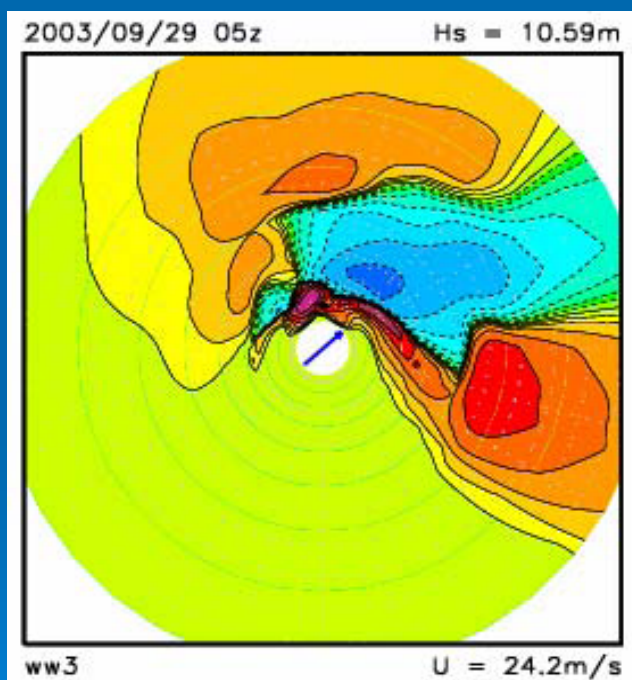
FBI



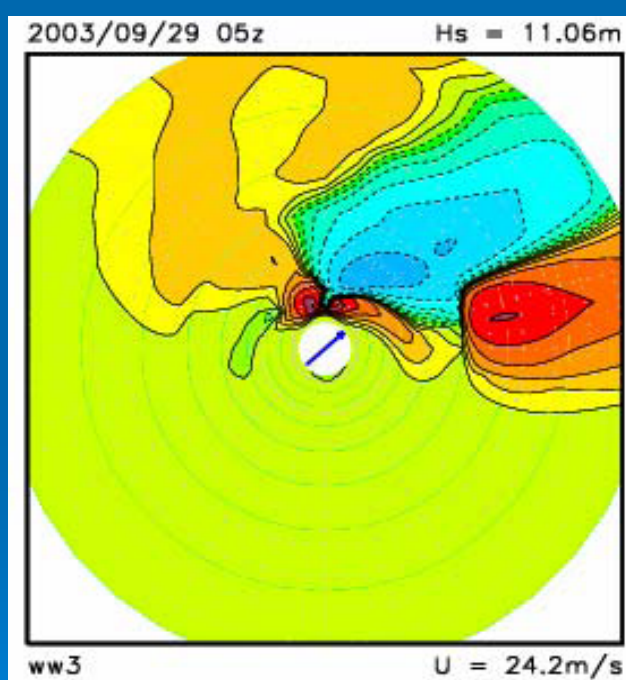
TSA

04UTC Sept 29 2003

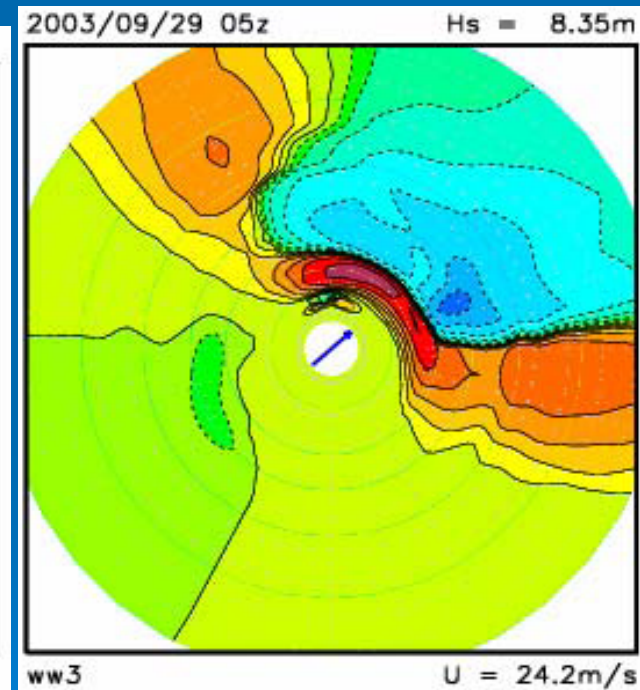
Snl



DIA



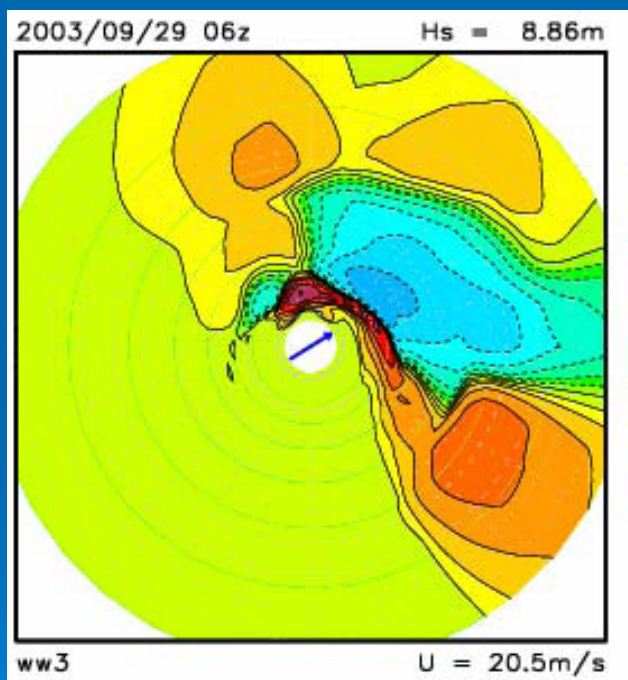
FBI



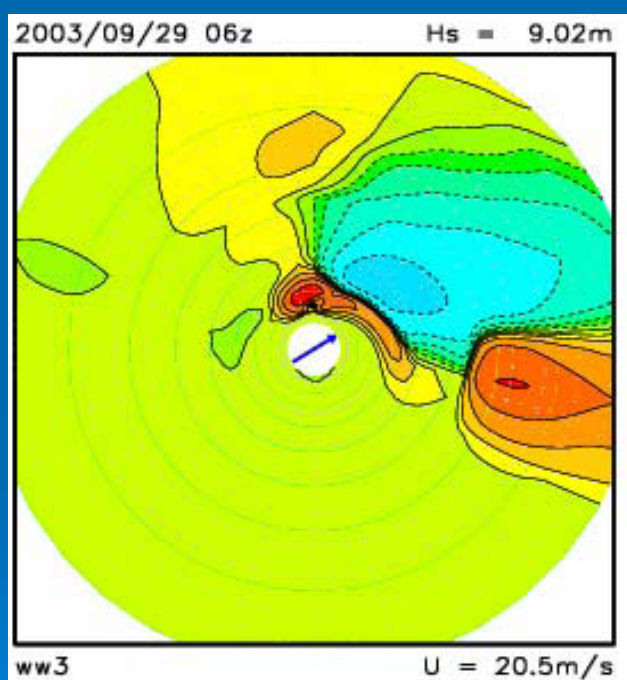
TSA

06UTC Sept 29 2003

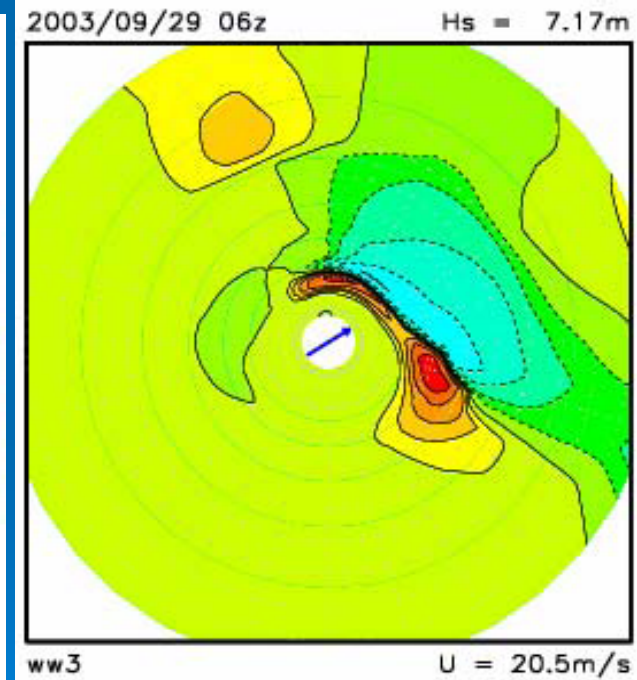
Snl



DIA



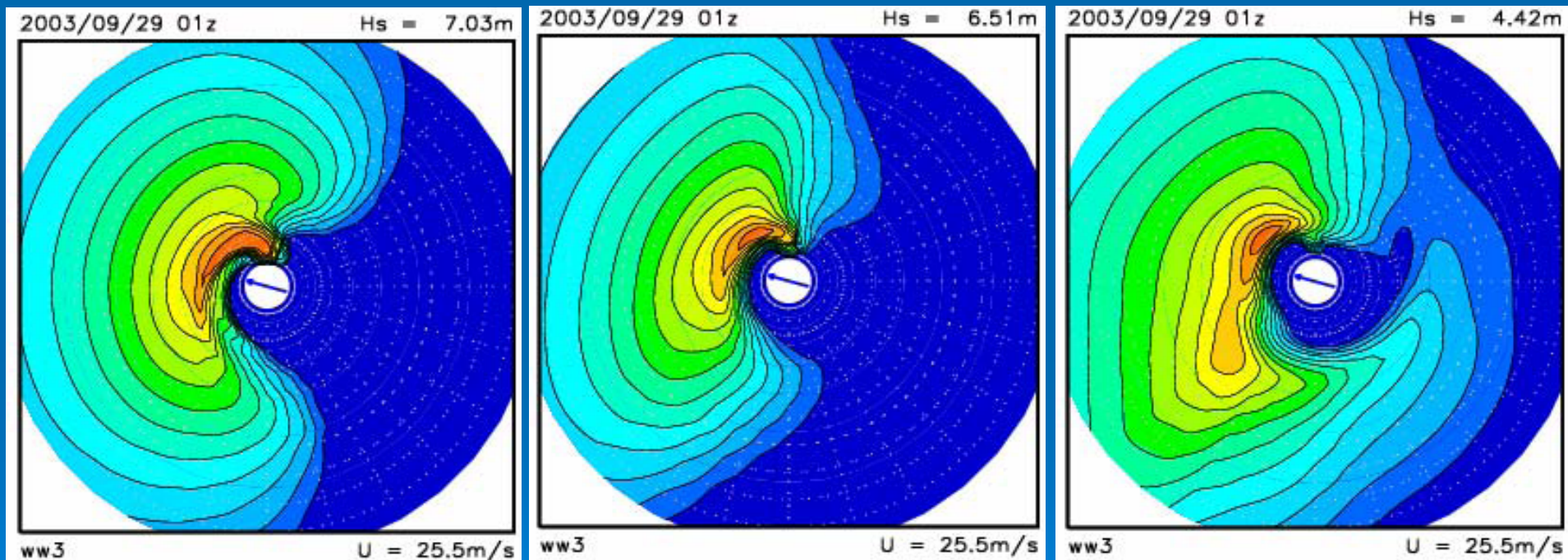
FBI



TSA

01UTC Sept 29 2003

2-d energy



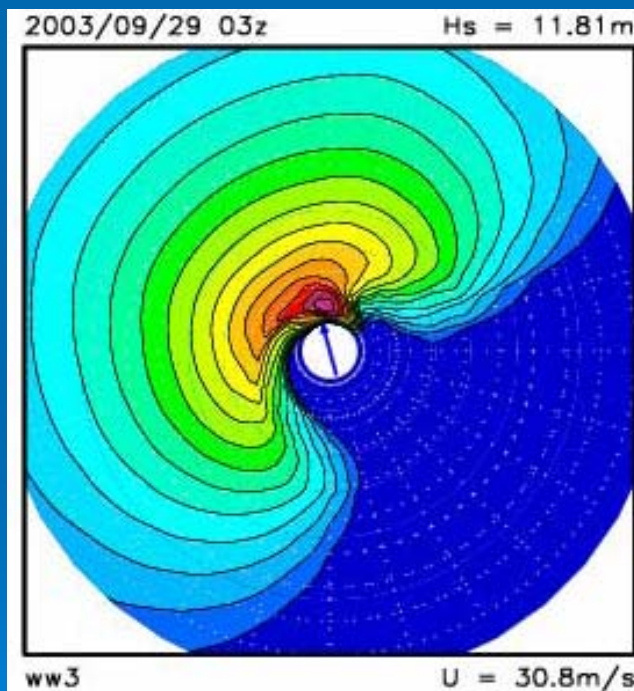
DIA

FBI

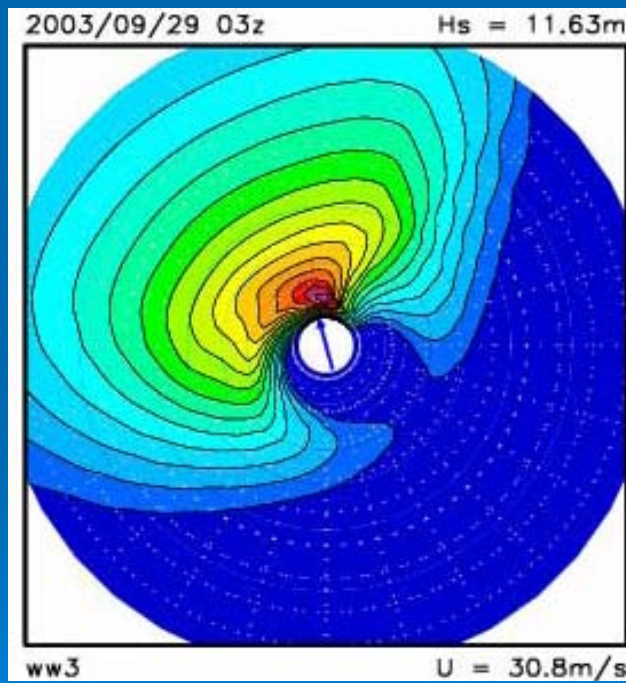
TSA

03UTC Sept 29 2003

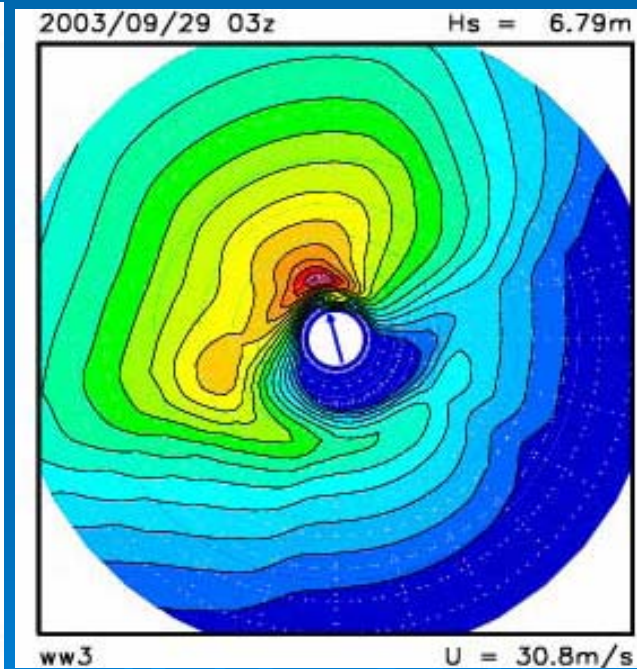
2-d energy



DIA



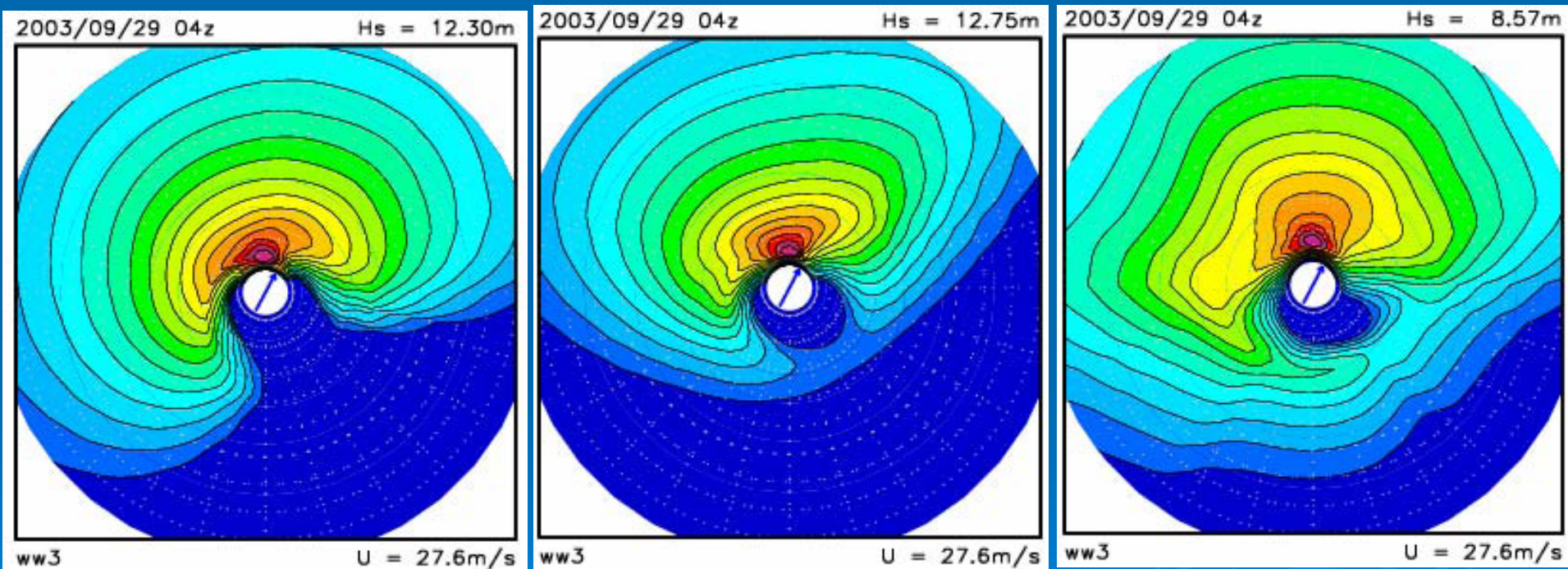
FBI



TSA

04UTC Sept 29 2003

2-d energy



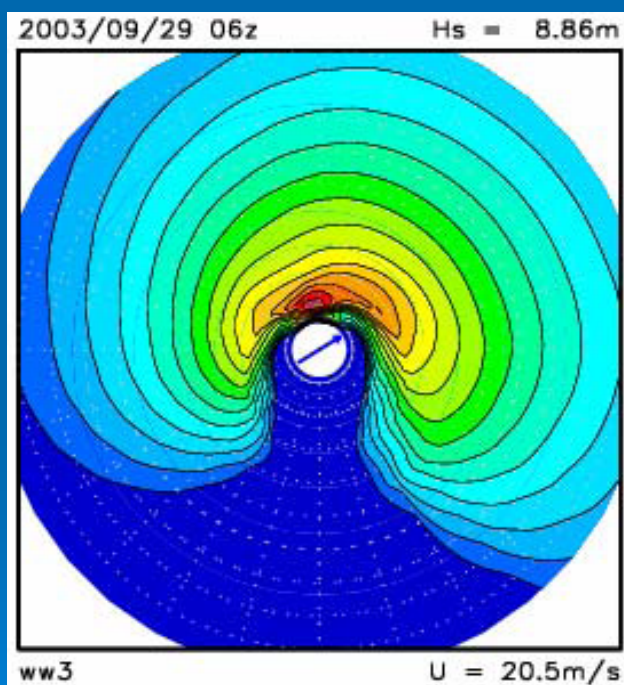
DIA

FBI

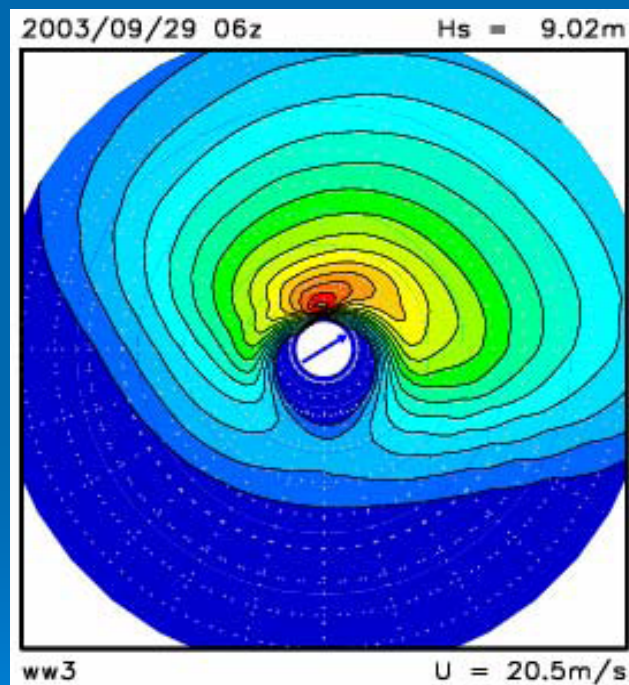
TSA

06UTC Sept 29 2003

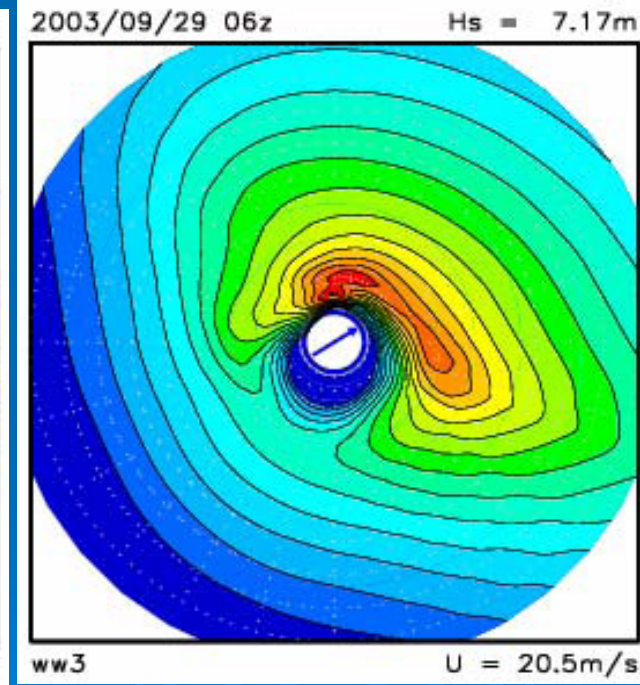
2-d energy



DIA



FBI

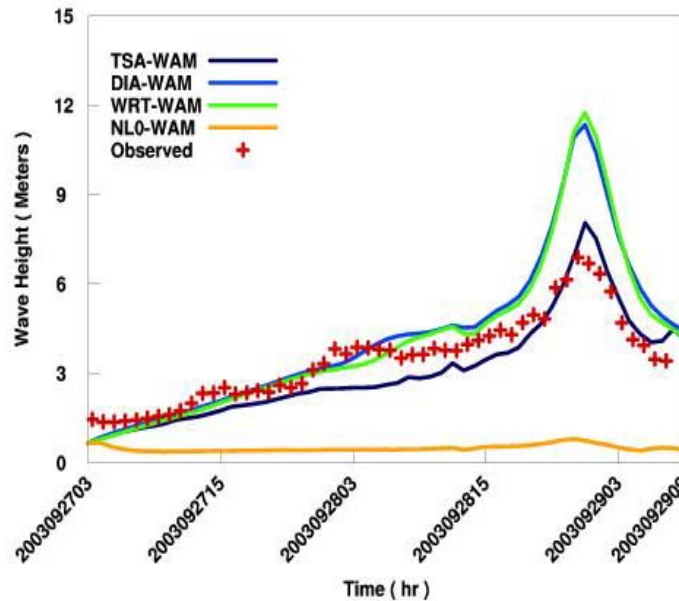


TSA

WAM-cycle3 for S_{in} , S_{ds}

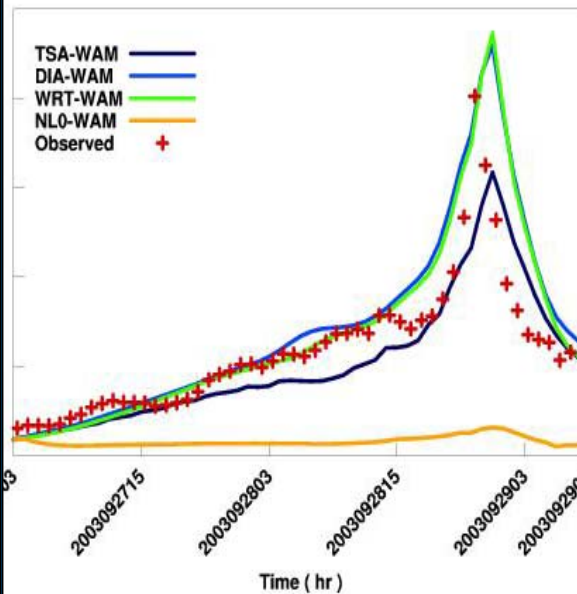
Wave Height [m]

Wave Height (Observed/Model Data Comparison)
Station: Buoy 44137

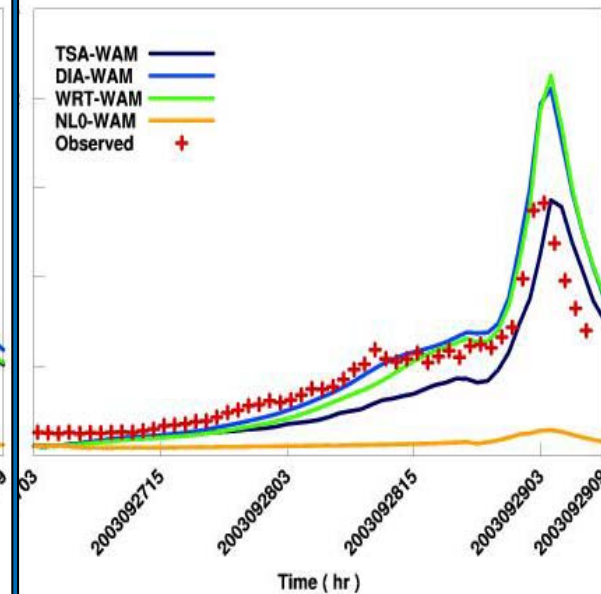


Buoy 44137

Wave Height (Observed/Model Data Comparison)
Station: Buoy 44258



Buoy 44142

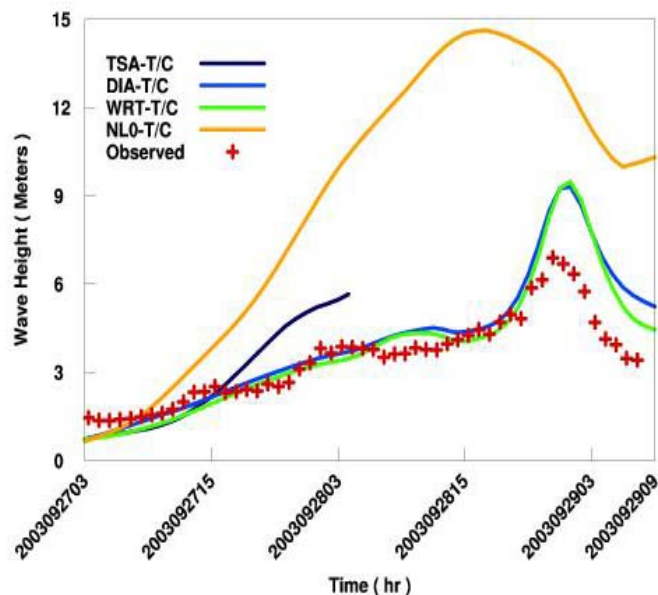


Buoy 44258

Tolman / Chalikov for S_{in} , S_{ds}

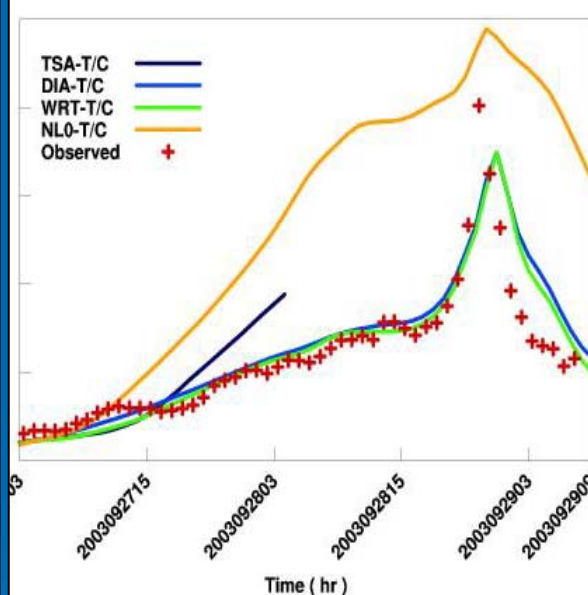
Wave Height [m]

Wave Height (Observed/Model Data Comparison)
Station: Buoy 44137

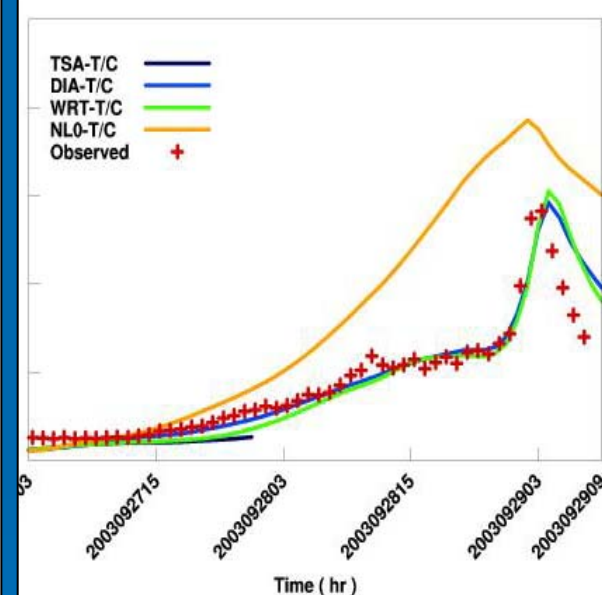


Buoy 44137

Wave Height (Observed/Model Data Comparison)
Station: Buoy 44258



Buoy 44142



Buoy 44258

Summary / Conclusions

1. original TSA works for simple growing wind-generated waves
2. doesn't work so well multi-peak spectra
3. can generalize by multiple broad-scale terms
4. hypothetical and real data
5. tuning? WAMcycle3 ? Tolman/ Chalikov ...

Acknowledgements: NOPP, Canadian Panel on Energy R & D