OCEAN WAVE MODELING AND FORECASTING SYSTEM

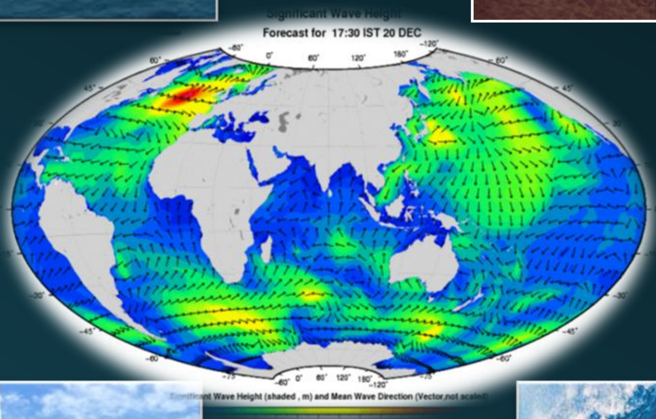
REMYA P. G.
ISG/OSF
INCOIS

Training Course on
'Remote Sensing of Potential Fishing Zones and Ocean State Forecast'
March 24-29,2014,INCOIS

NUMERICAL MODELING OF OCEAN WAVES

Why model ocean waves ?

- Safe navigation
- Public safety
- Design of offshore and coastal infrastructures
- Recreation



- What wave model predicts ?

- Only wind generated waves

- How waves evolve as changing wind fields acts on the surface of the ocean

- What are the process affecting the energy of the waves ?

- Gain from the external environment (Source)
- Advection (rate of energy propagated into and away from the location)
- Losses due to dissipation (Sink)

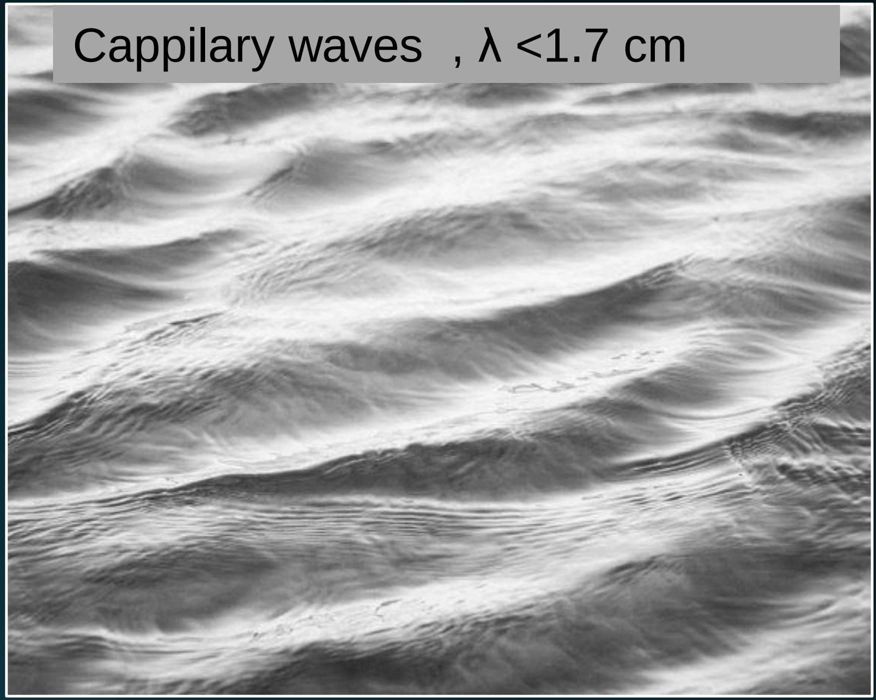
SOURCE AND SINK FOR WAVE ENERGY

- Wave growth by the wind
- Wave decay due to
  - Whitecapping
  - Bottom friction
  - Depth-induced wave breaking
- Nonlinear transfer of wave energy

WAVE GROWTH BY THE WIND

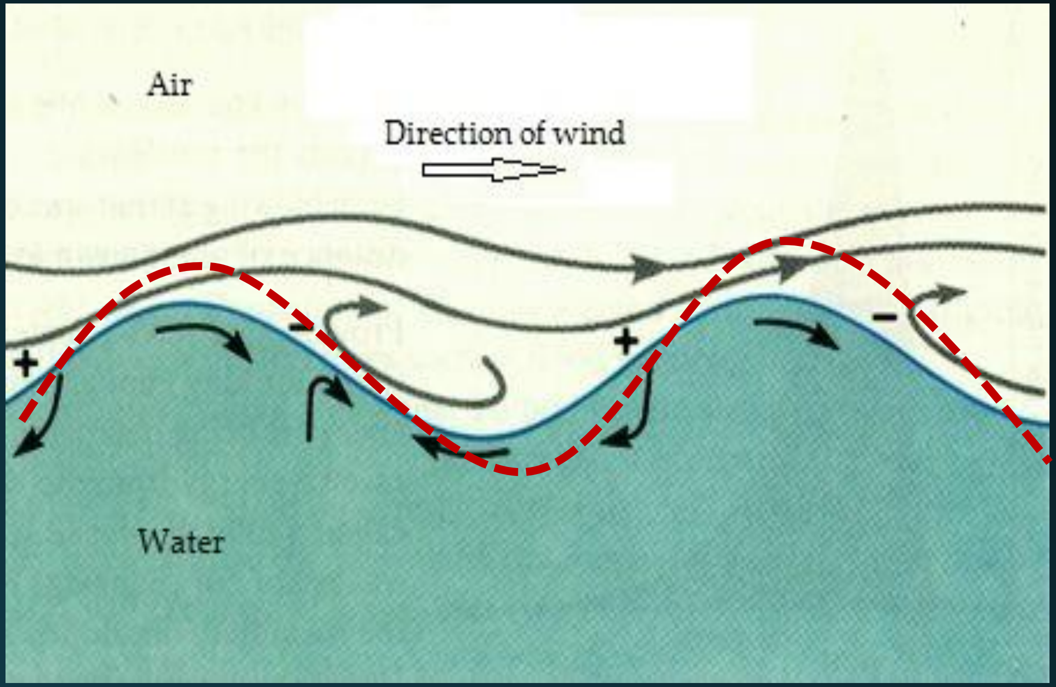
- Wind - wave generation
  - Philips- Miles theory of wave generation (Philips,1957; Miles,1960)
  - The small pressure fluctuations associated with turbulence in the air flow are sufficient
    - to induce small perturbations on the sea surface
    - to support a subsequent linear growth as the wavelet move in resonance with pressure fluctuations

Philips (1957)



Miles,(1960)

- The structure of the air flow at the critical height** determines the force exerted by the wind on the sea surface



- Deformation of air flow over existing waves produces
  - a low pressure on the leeward face
  - A high pressure on the windward face

- The air flow drags the crest and pushes down the trough

*** At some small height above the water usually less than few centimetres, the air and water are moving at the same speed.*

BASIC COMPONENTS TO THE WAVE GROWTH

- WIND SPEED
- FETCH
- DURATION

o WIND SPEED

- Wind speed is greater than the wave speed, the wave will grow

- Wind speed = Wave speed, the downward force on the windward side of the crest and the upward force on the leeward side of the crest will no longer exist

- Wind speed is slower than the wave speed, the wind will have no effect on the wave, wave growth will not occur

Individual wave speeds for various wave periods at a constant wind speed

$$C = \sqrt{\frac{gL}{2\pi}} = 2.26\sqrt{L} = 3.02\ T$$

Wave Period (s)	Wave Speed (kt)	Duration 12 kt Wind Speed (hr)	Duration 30 kt Wind Speed (hr)
2	6	< 1	< 1
4	12	3	1.25
6	18	15	5
8	24	96	18
10	30	> 96	60

Wave growth continued...

FETCH

- Distance over which the wind generally blows from a constant direction and at a constant speed

- Winds that abruptly speed up, slow down, or change direction – New fetch to be determined

- Focus only on the fetches that will propagate waves into the forecast area

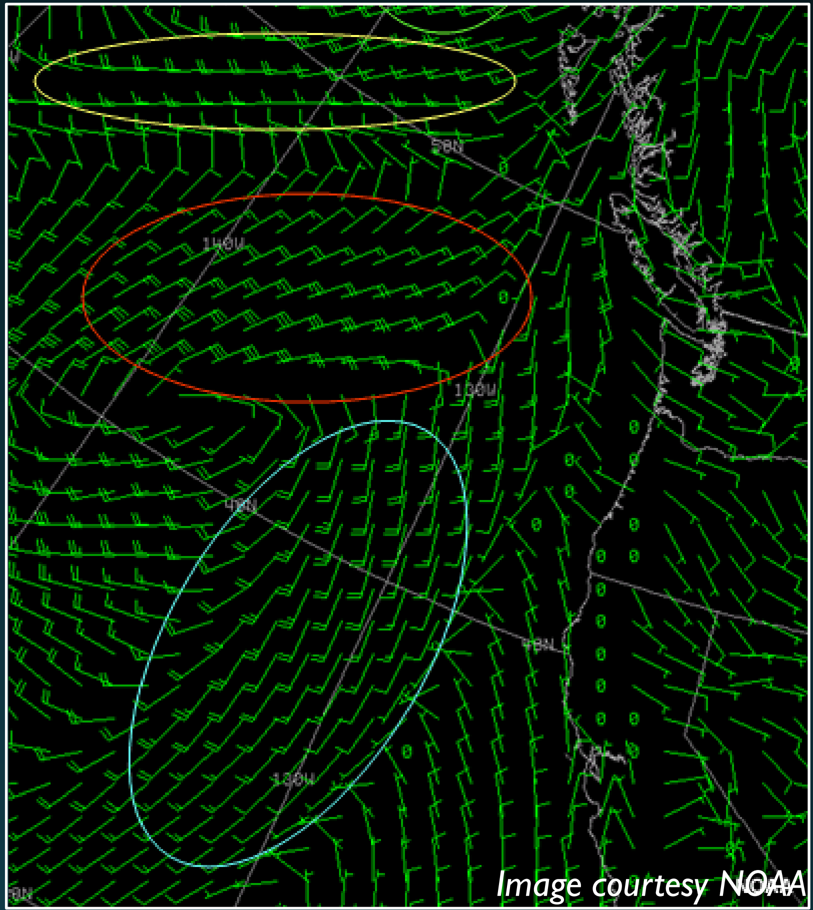


Image courtesy NOAA

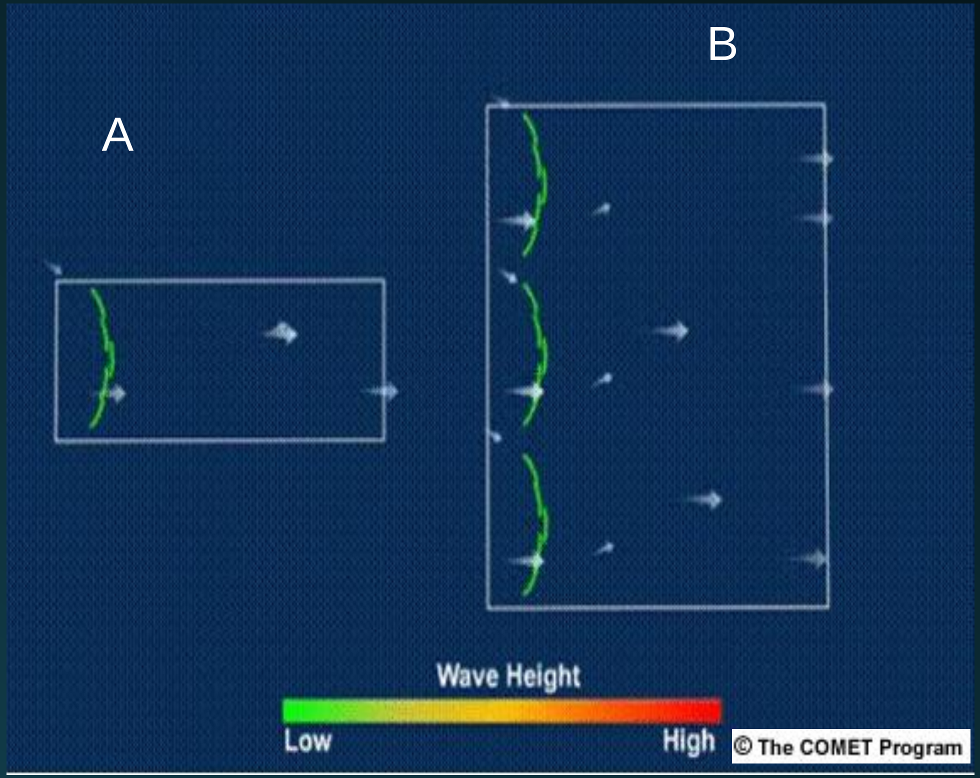
Continued…

- A general wind direction as well as small variations

- Predominant wind direction generates larger waves exiting from the downwind end of the fetch

- Wave growth is also limited by the size of the fetch region

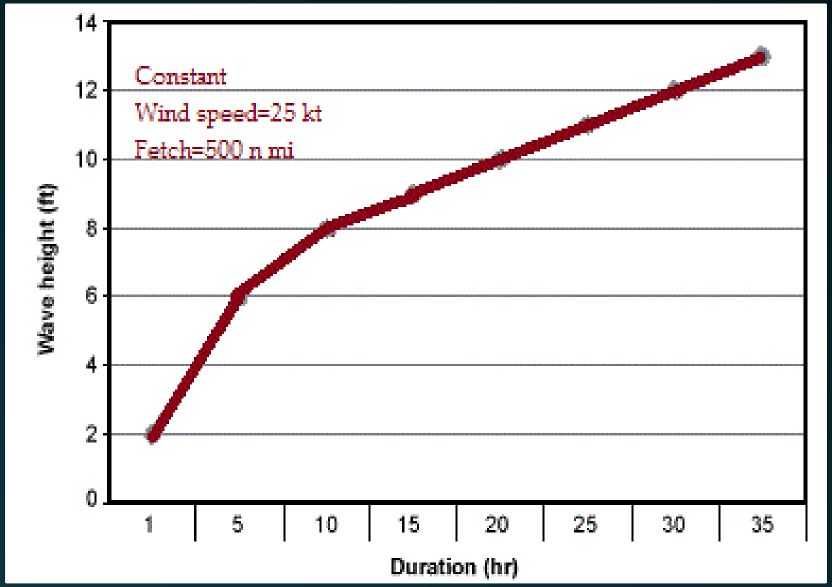
- Fetch size can be constrained primarily by land mass blocking and wind area



o WIND DURATION

➢ Duration is the length of time a wind in a given fetch affects wave growth

➢ Given a high wind speed and long fetch length, the longer the wind blows, the larger the waves will grow



WIND SEA AND SWELL

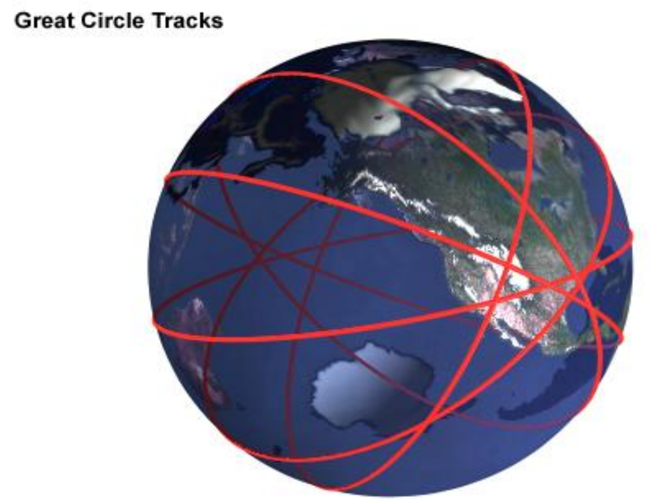
- Seas refer to short-period waves that are still being created by winds or are very close to the area in which they were generated

- Swell refers to waves that have moved out of the generating area, far from the influence of the winds that made them

- This process is called propagation

WAVE PROPAGATION

- Waves run along the great circles
- Wave energy travels at the group velocity (Cg)
- Deep water , Cg=1/2 phase velocity
- Shallow water, Cg= phase velocity



A great circle track is the shortest distance between two points on a sphere

WAVE-WAVE INTERACTIONS

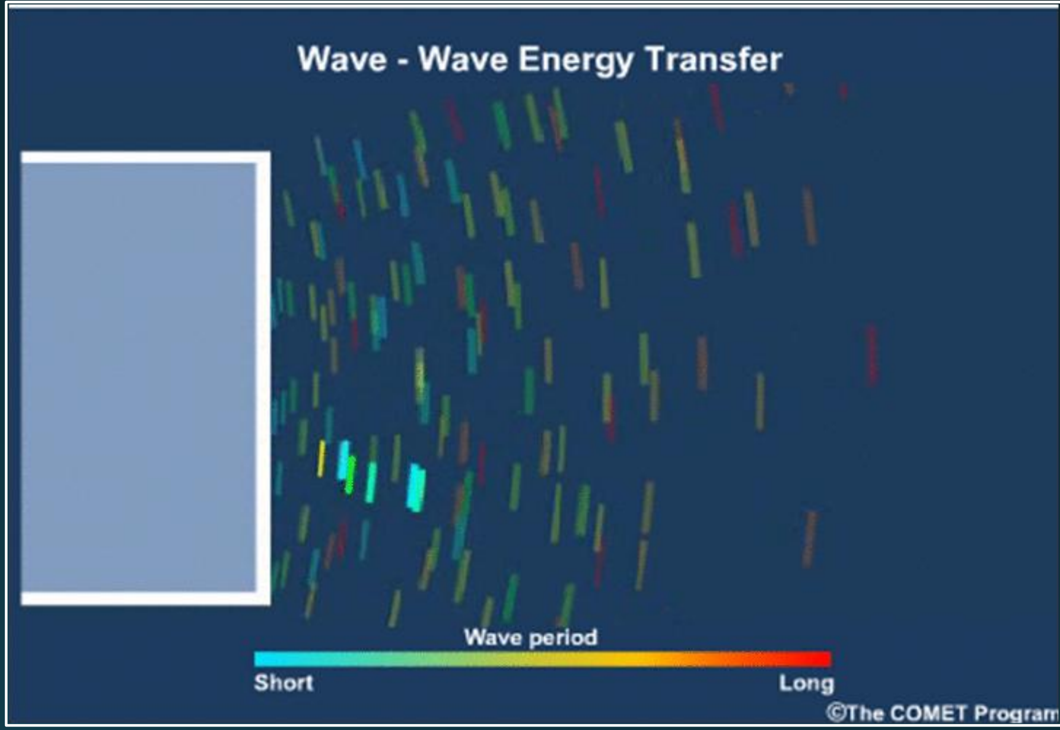
- The transfer of energy *amongst* the waves, i.e., from one wave component to another, by resonance

- No energy is gained or lost

- Energy transfer from the short-period waves to longer-period waves

- cause a smoothing-out of the sea surface from chaotic to more organized (i.e., from sea to swell)

- This process is more active close to the fetch

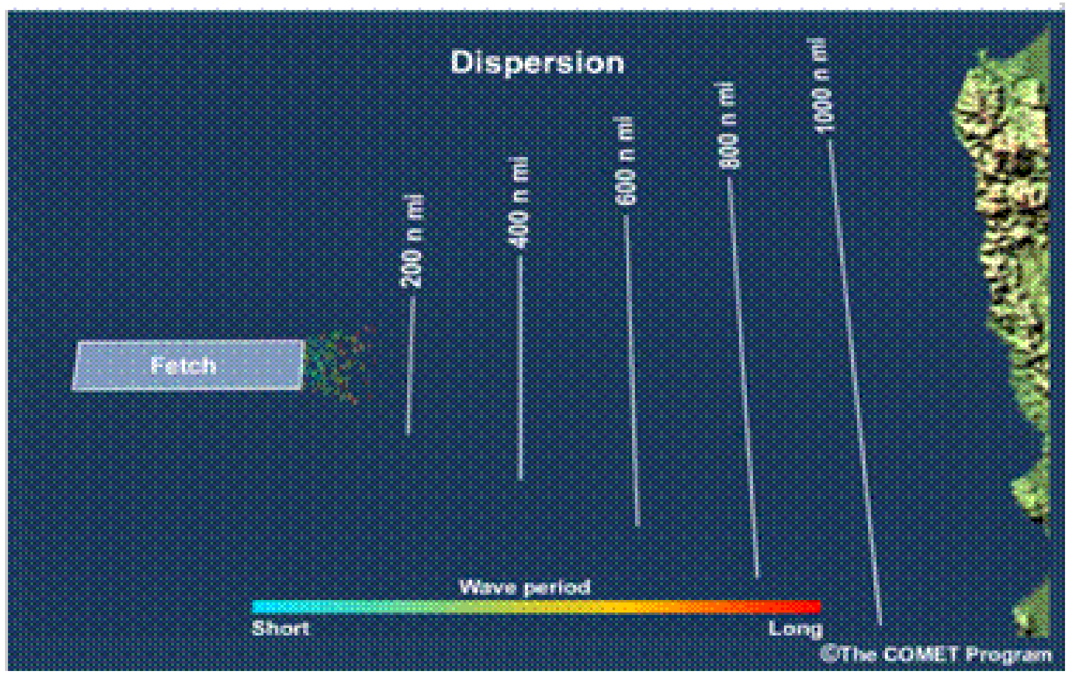


DISPERSION

- For deep water waves, wave speed is a function of wavelength (c= sqrt(gλ/2π)) and wavelength is directly related to wave period

- The longer the wave period, the faster a deep water wave moves; the shorter the wave period the slower the wave moves

- Swell is more uniform and regular than seas because wave energy becomes more organized as it travels long distances



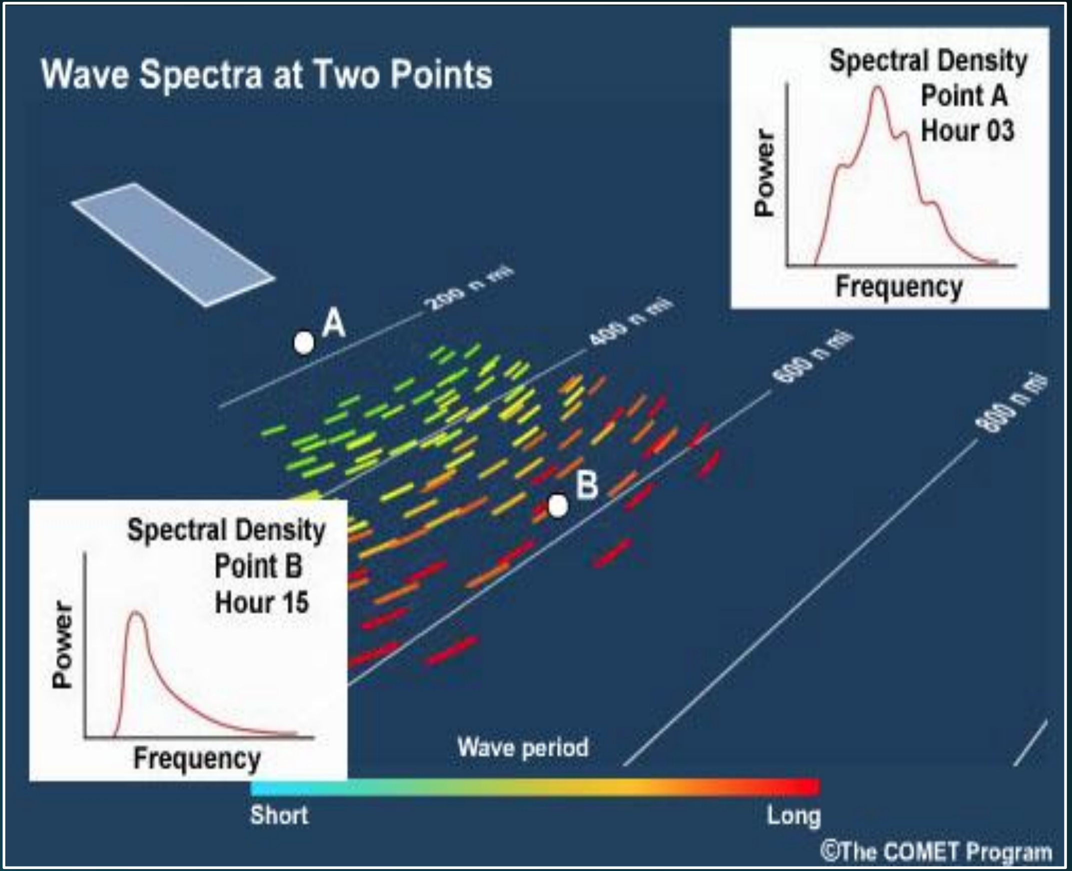
Why significant swell period increases as the propagation distance increases?

- As the swell group moves out of the fetch, nonlinear processes transfer wave energy from short- to long-period swell.

- Dispersion is also at work as the group moves further

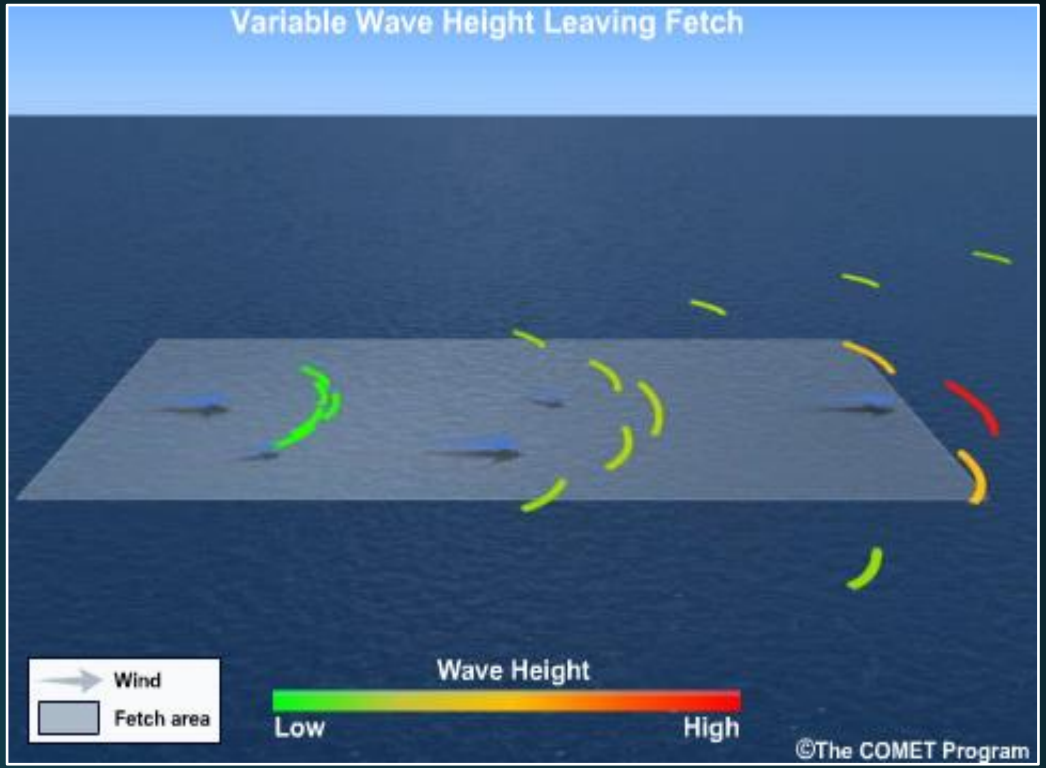
- Statistical calculation of significant swell period thus gives a slightly higher swell period at A.

- Dispersion cause the overall individual swell period values to increase at the group's leading edge,



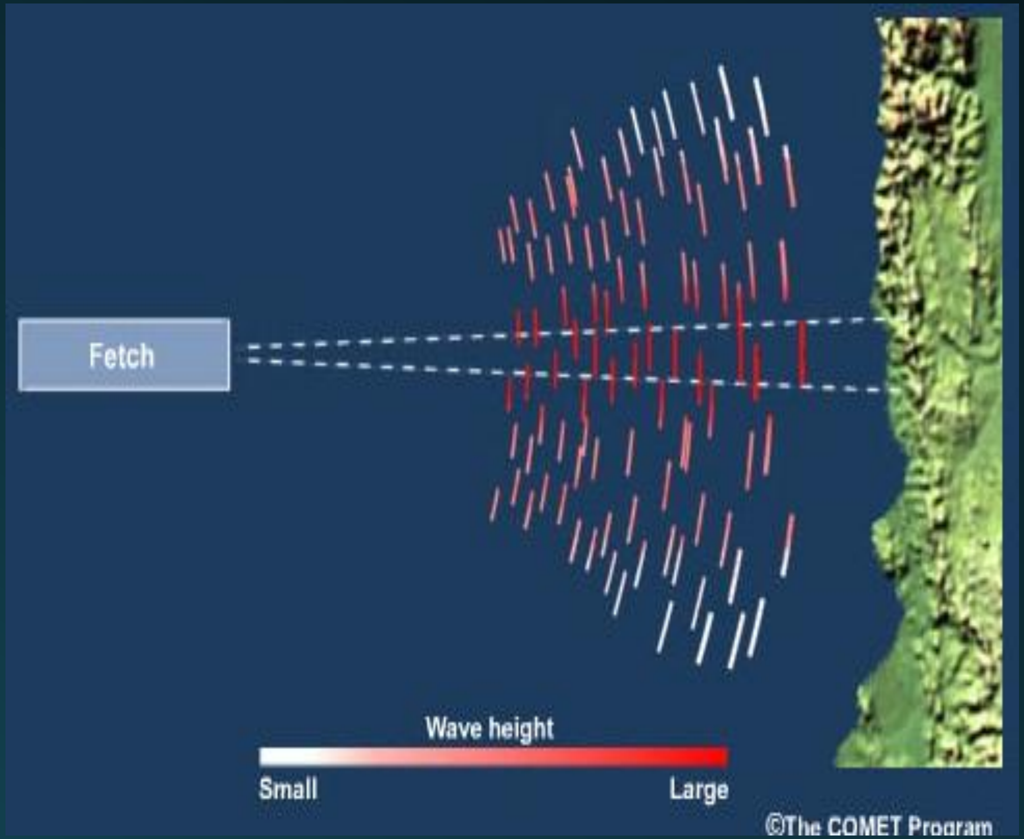
○ Angular spreading

- Waves are generated in a wide range of angles around the mean wind direction within a fetch
- The energy is concentrated parallel to the prevailing wind direction and decreases rapidly with increasing angle to it
- Wave energy is not distributed evenly along the significant width at the fetch exit region



Continued…

- Maximum wave heights will occur along the centreline of the fetch
- Largest swell impact will occur where the great circle path of the centreline of the fetch intersects the final destination
- The largest swell height will be found closest to the great circle path extending from the mean wind direction in the fetch area, with decreasing swell height to either side
- Angular spreading is the lateral spreading of swell energy.



WAVE DECAY

- Whitecapping

- A dissipation process that occurs in any water depth
- Depends mainly on the steepness of the waves (steepness=H/ λ=*1/7*)
- Wind input alone makes the wave height grow indefinitely ; whitecapping limits the wave height

Wave decay continued…

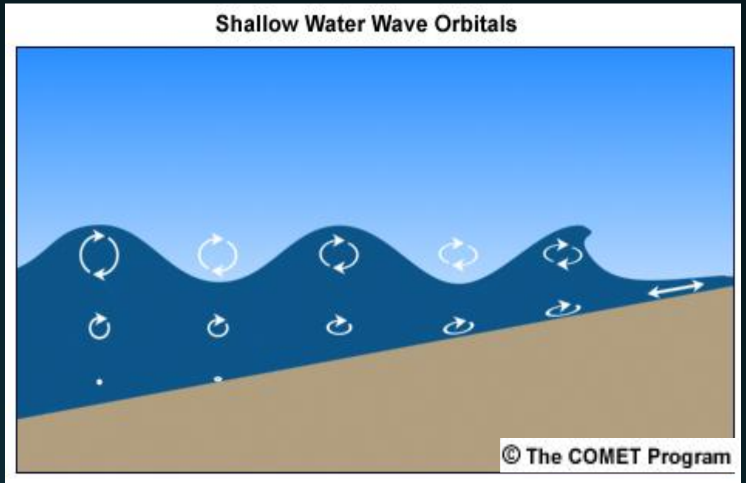
- Bottom friction

➢ Water particle motion in deep is nearly circular called orbital

➢ Orbital gradually diminishes with depth and touch bottom when waves propagate into shallow** water

➢ Wave energy is dissipated due to friction between the bottom and the orbital motion

➢ The amount of dissipation depends on the roughness of the bottom



****Deep Water:** *Water is deeper than* ***one-half*** *of the wavelength*

Shallow Water: *Water depth is less than or equal to* ***one-twentieth*** *of the wavelength*

Transition Zone: *Water depth is between the deep- and shallow-water thresholds*

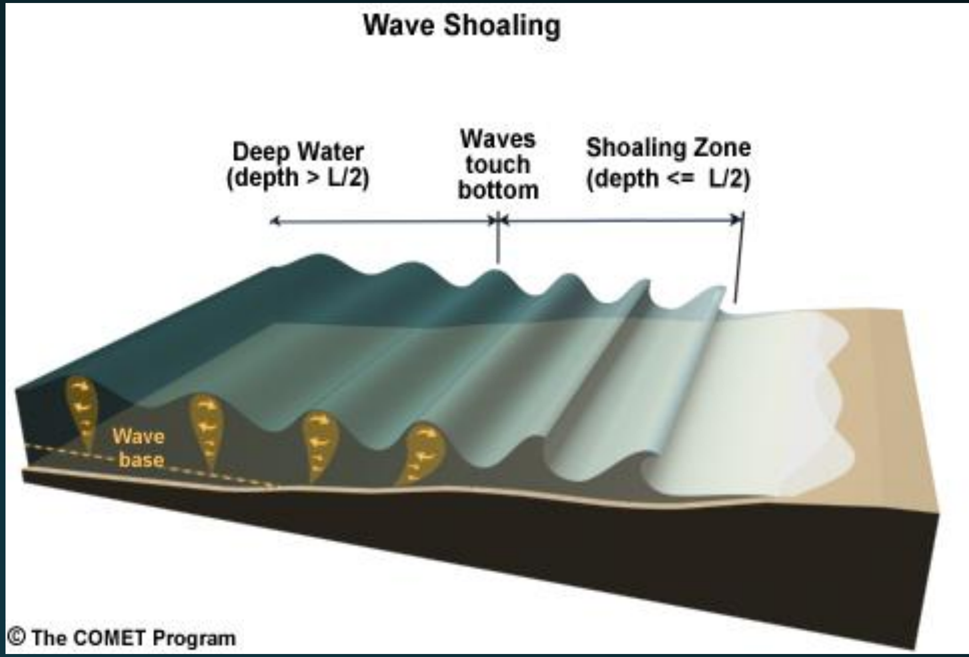
o Shoaling

- As a wave enters the transition zone, the wave bottom begins to drag on the sea floor causing the wave to slow down

- This dragging effect can be attributed to simple friction between the wave and the sea floor

- Waves decelerate as they enter shallow water

- Since wave period is always conserved, (c= *λ/T*), any decrease in speed ∞ decrease in wavelength



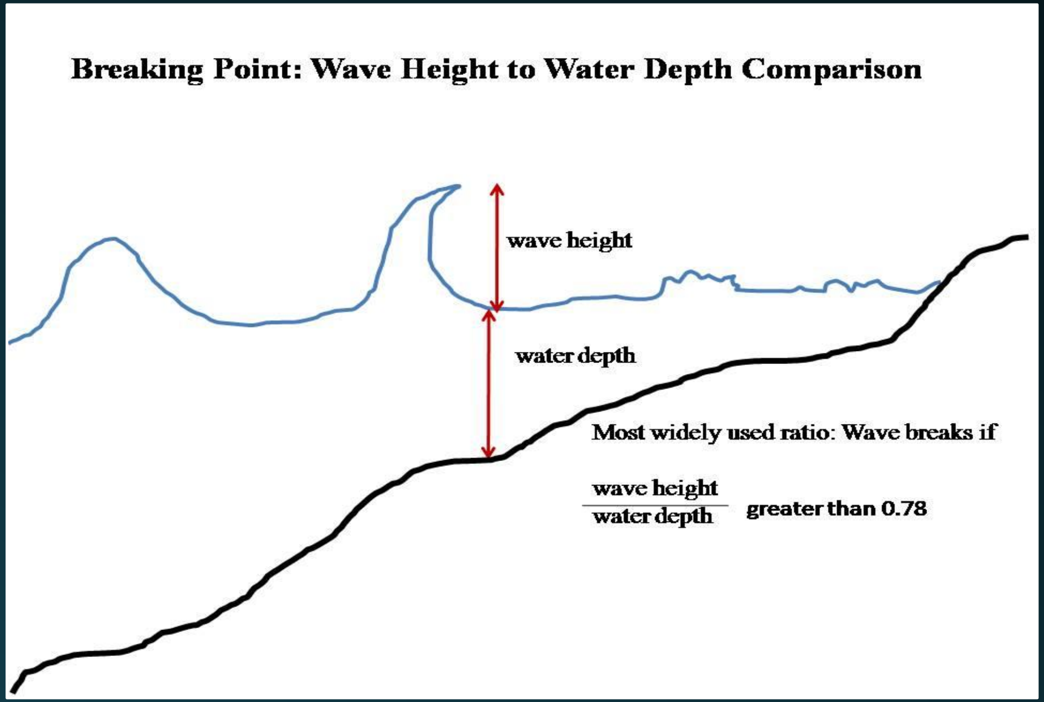
Shoaling continued

- Wave energy becomes concentrated into a narrower and slower-moving band, its kinetic energy is converted into the potential energy of a slower, taller wave

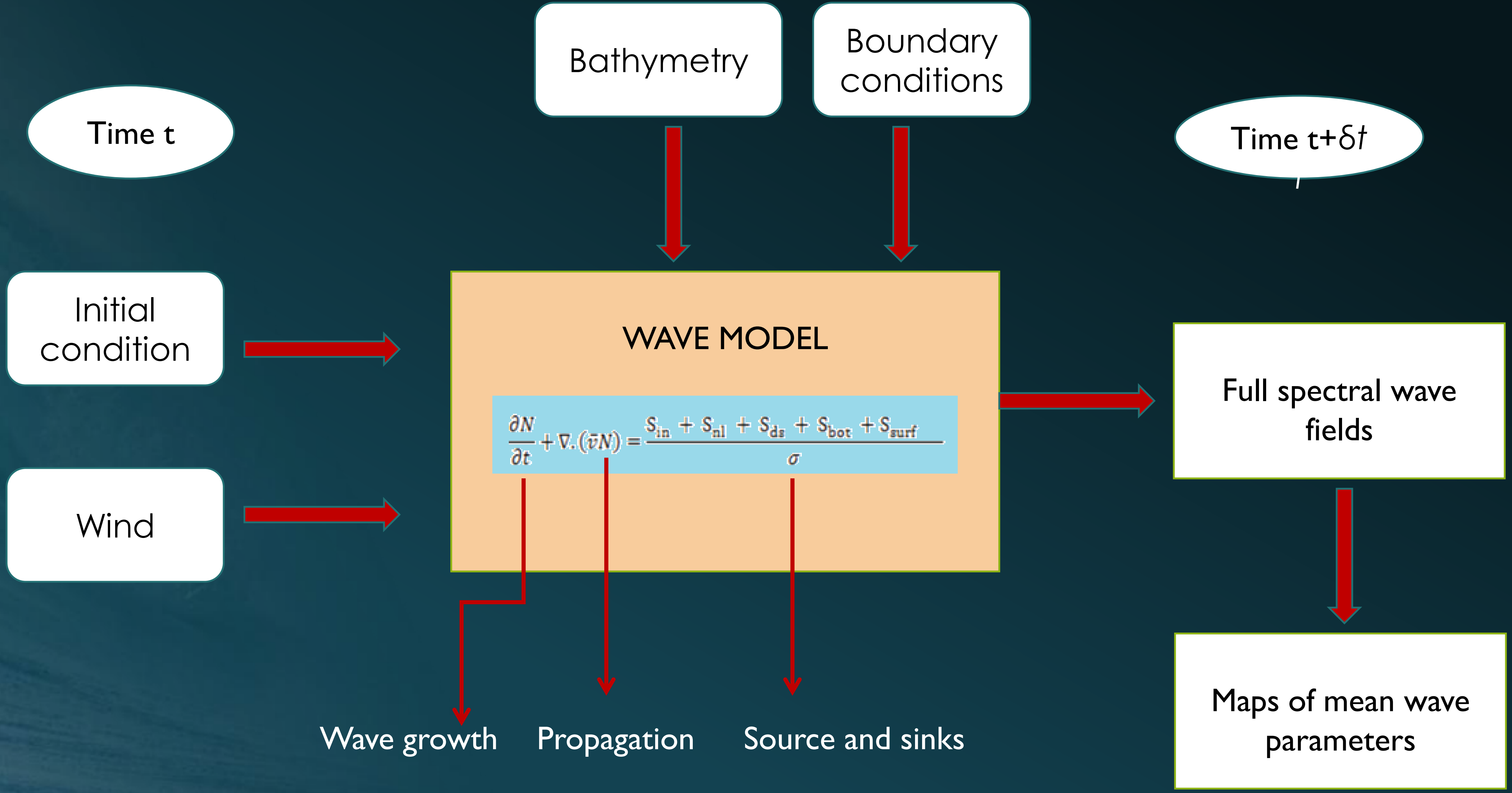
- Shoaling reduces wavelength and speed, while increasing wave height

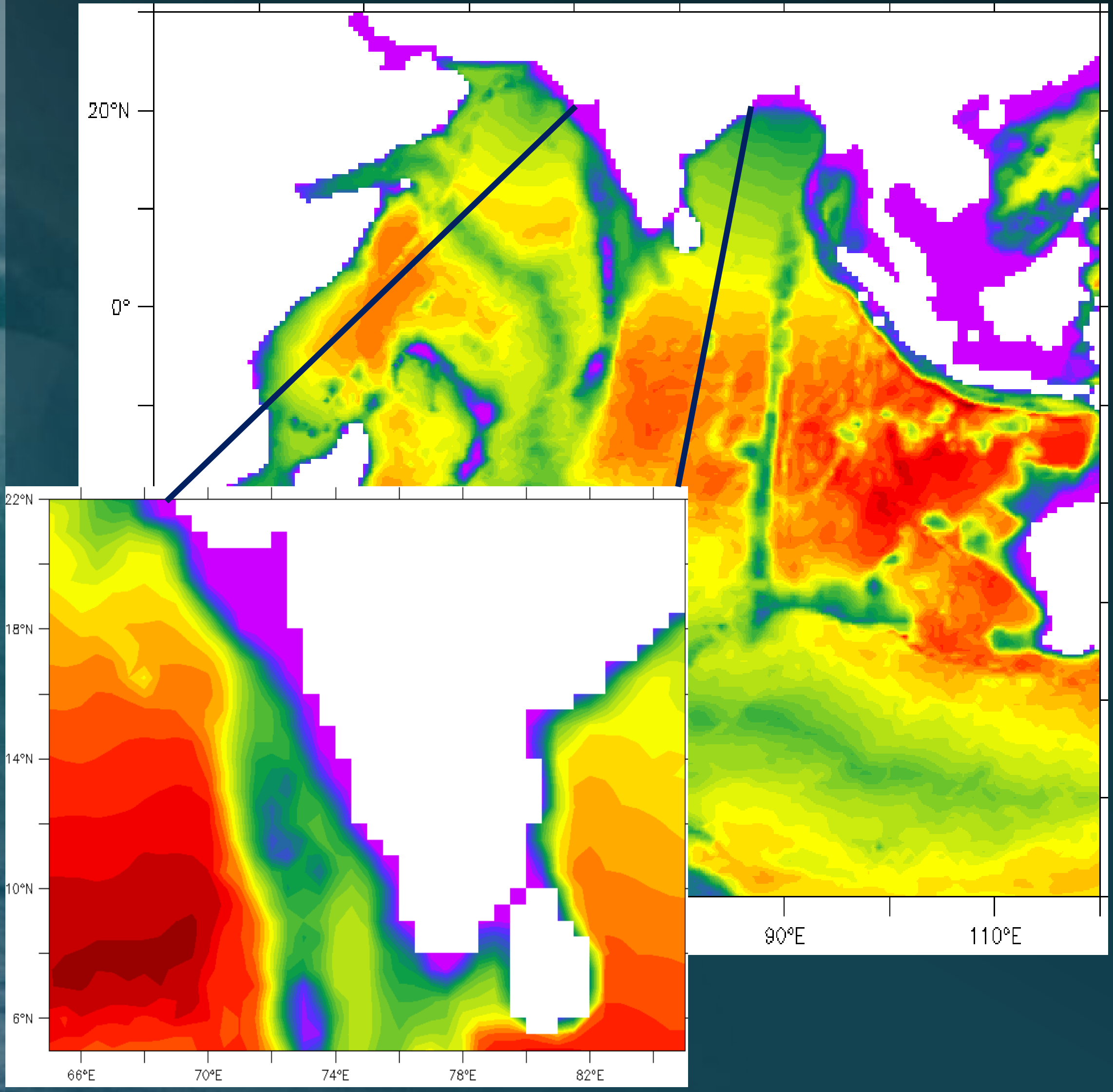
o Depth-Induced Wave Breaking

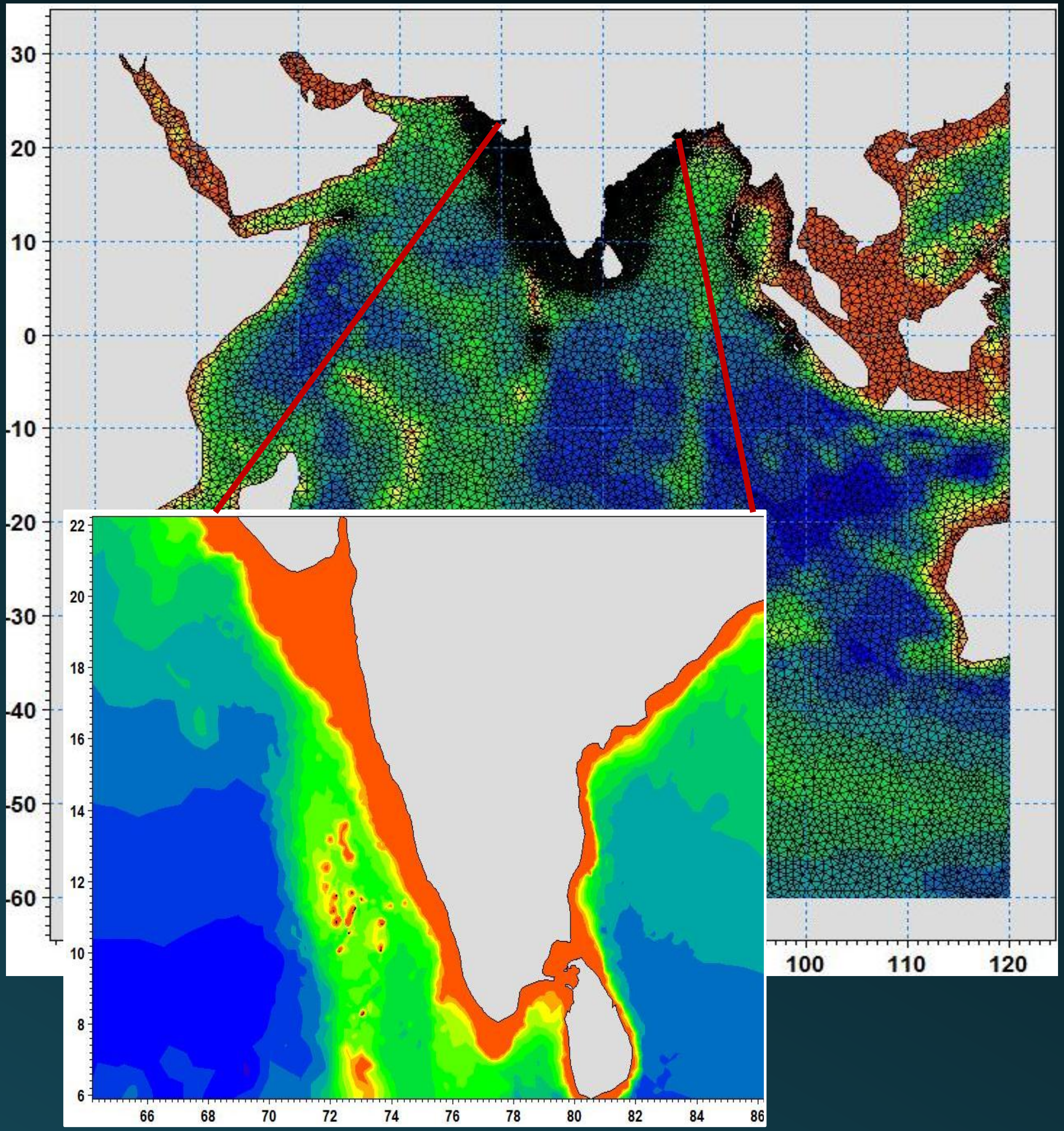
- Shoaling leads to an increase in wave height
- Waves begin to break when the significant wave height exceeds roughly one-half the depth
- Breaking rapidly increases as the ratio of wave height to depth grows



How the wave model works ?

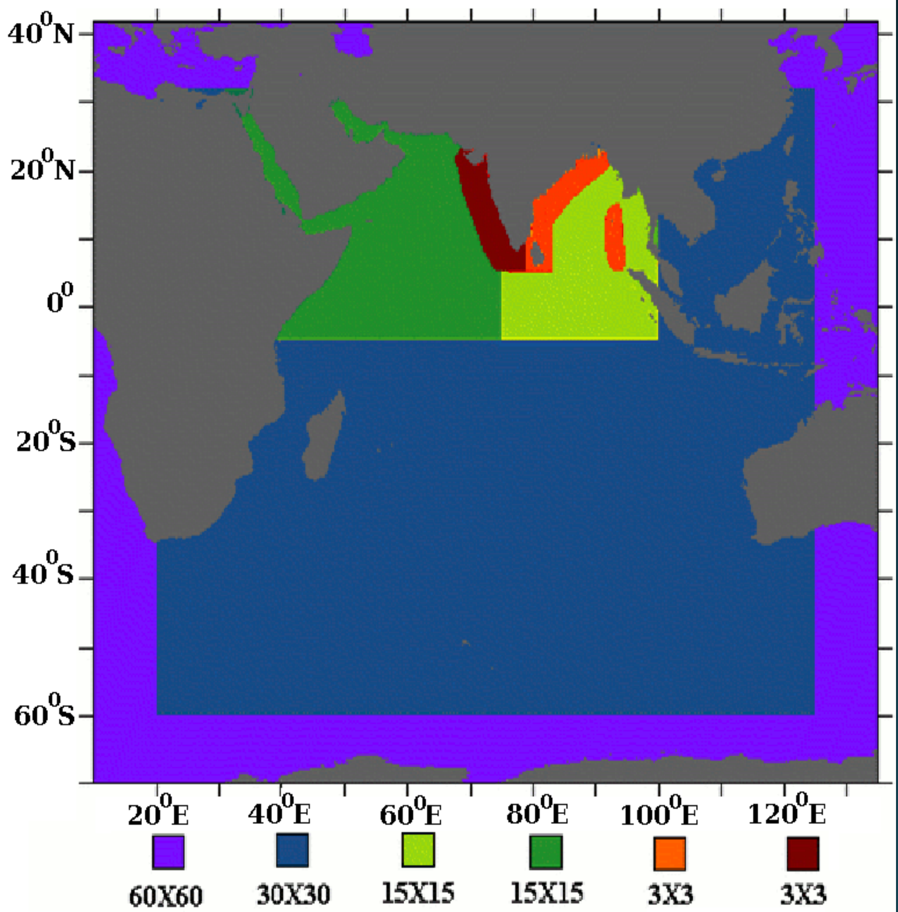






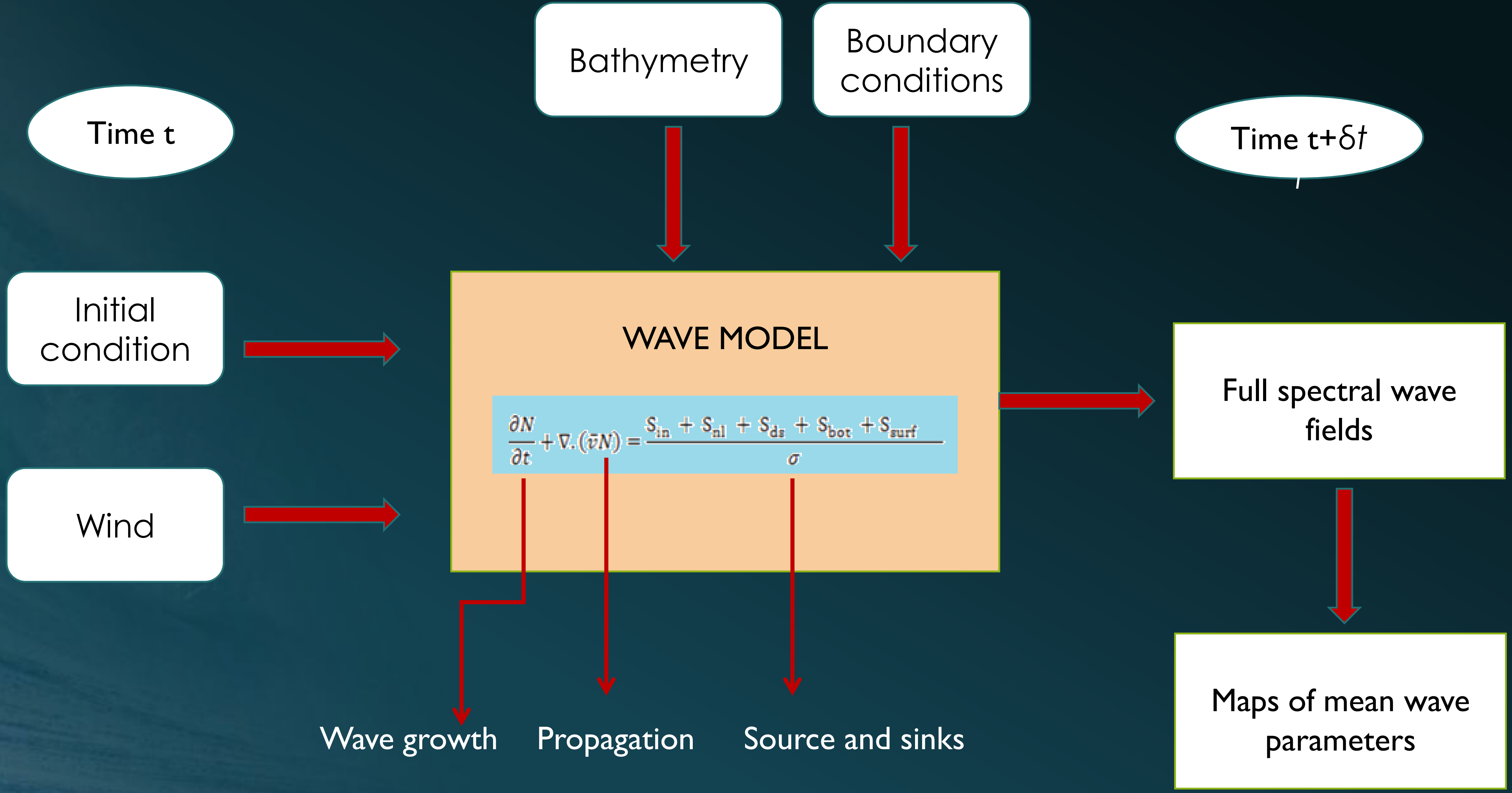
Bathymetry data- ETOPO ,(*www.ngdc.noaa.gov › ... ›* *Bathymetry & Relief*)
Modified ETOPO, (*www.nio.org,* Sindhu et al. , 2007),GEBCO, (*www.**gebco**.net)*

WAVEWATCHIII Multi-Grid setup at INCOIS

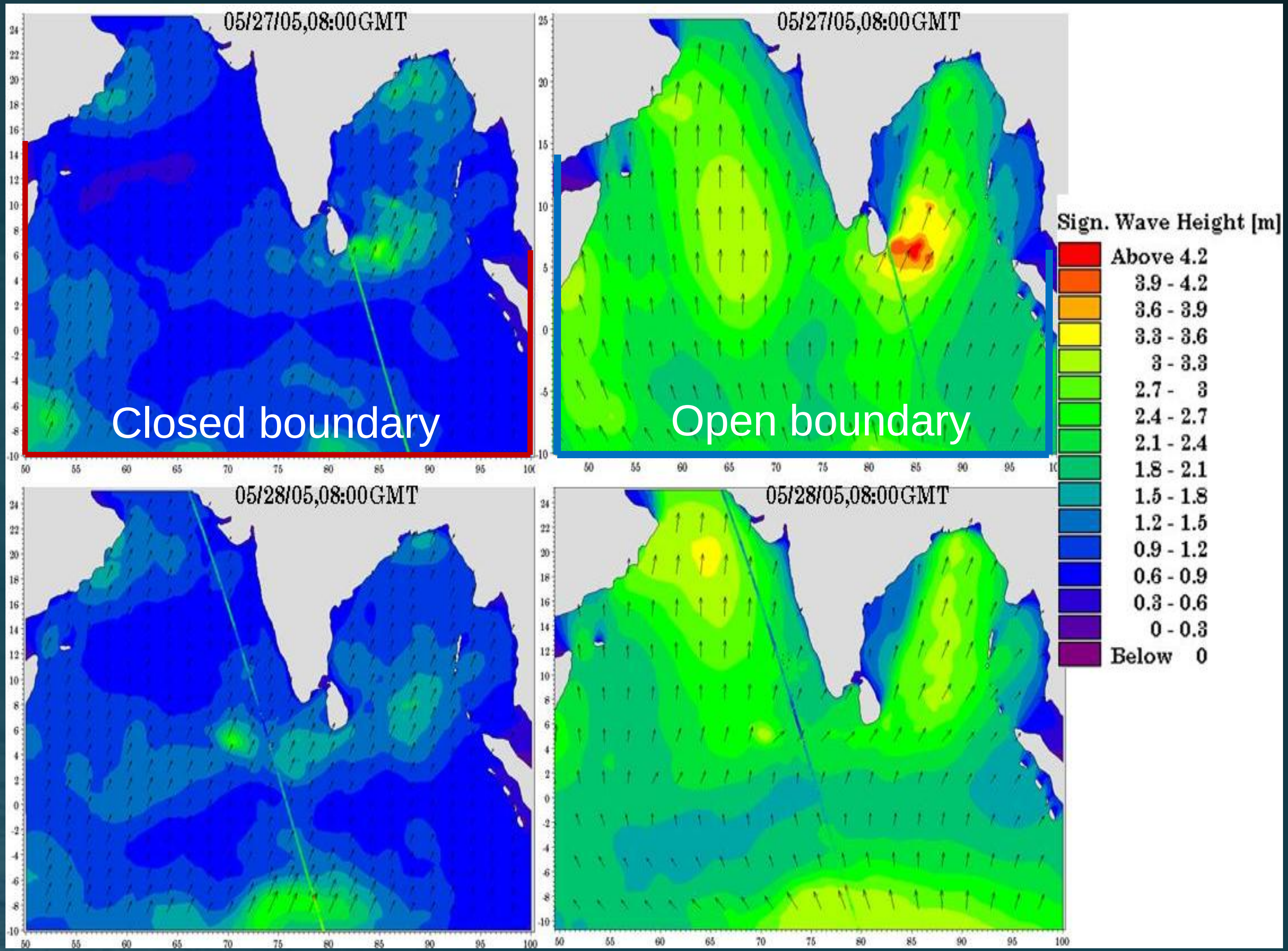


1 deg Southern Hemisphere grid
0.5 deg Indian Ocean grid
0.25 deg Arabian Sea grid
0.25 deg Bay of Bengal grid
0.05 deg West Coast grid
0.05 deg East Coast grid

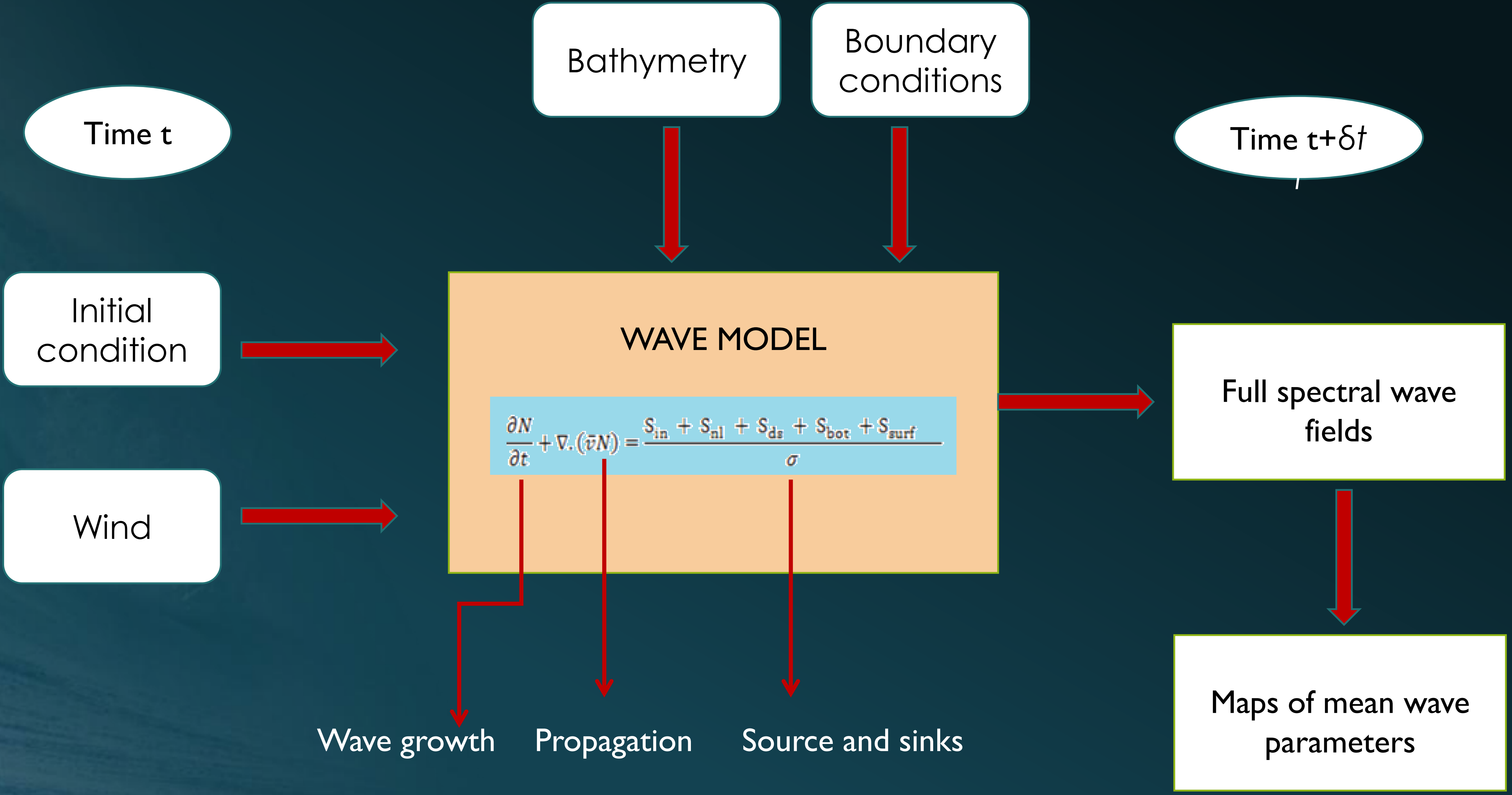
How the wave model works ?



Importance of accurate boundary condition



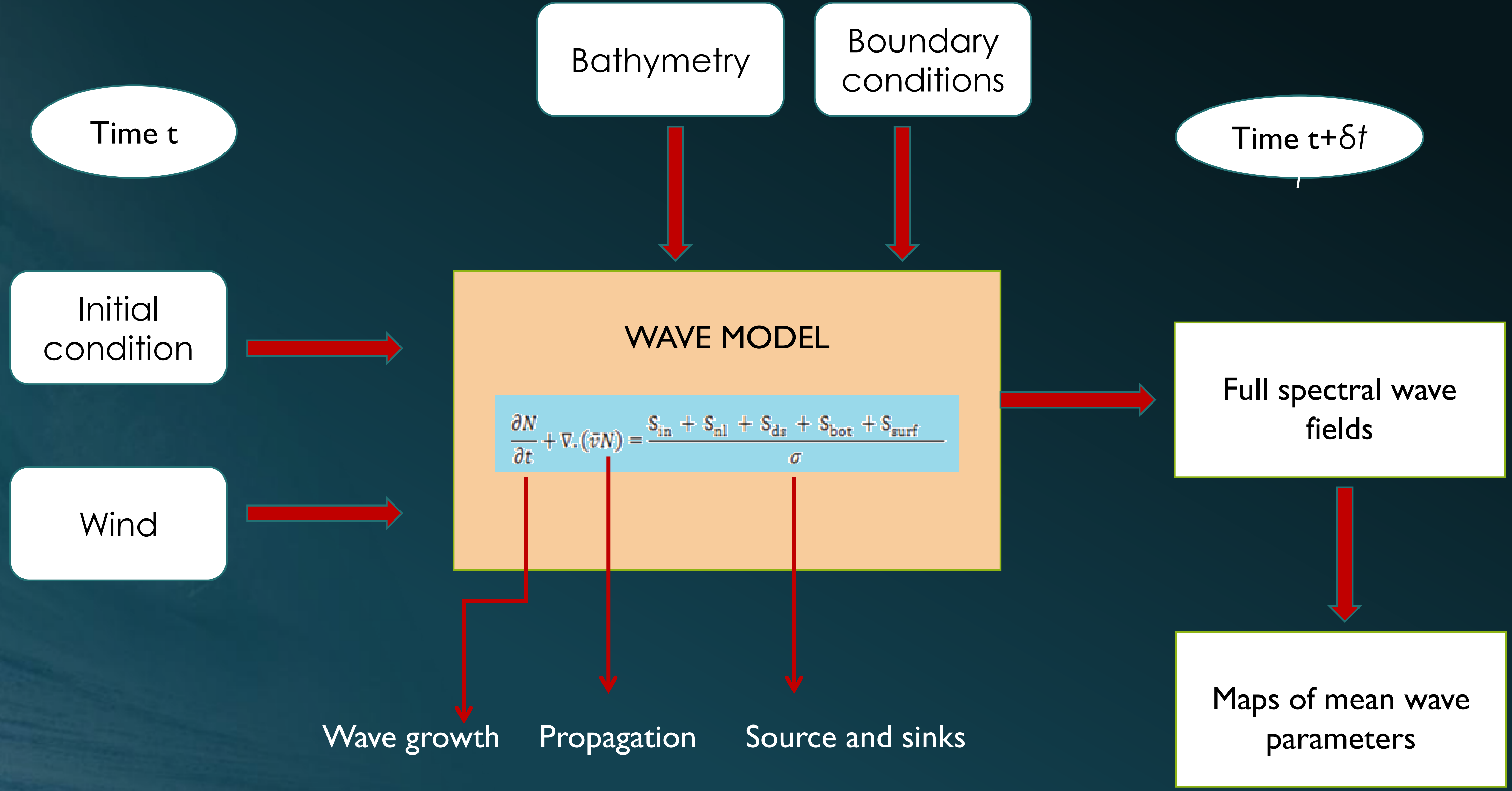
How the wave model works ?



Three different types of initial conditions

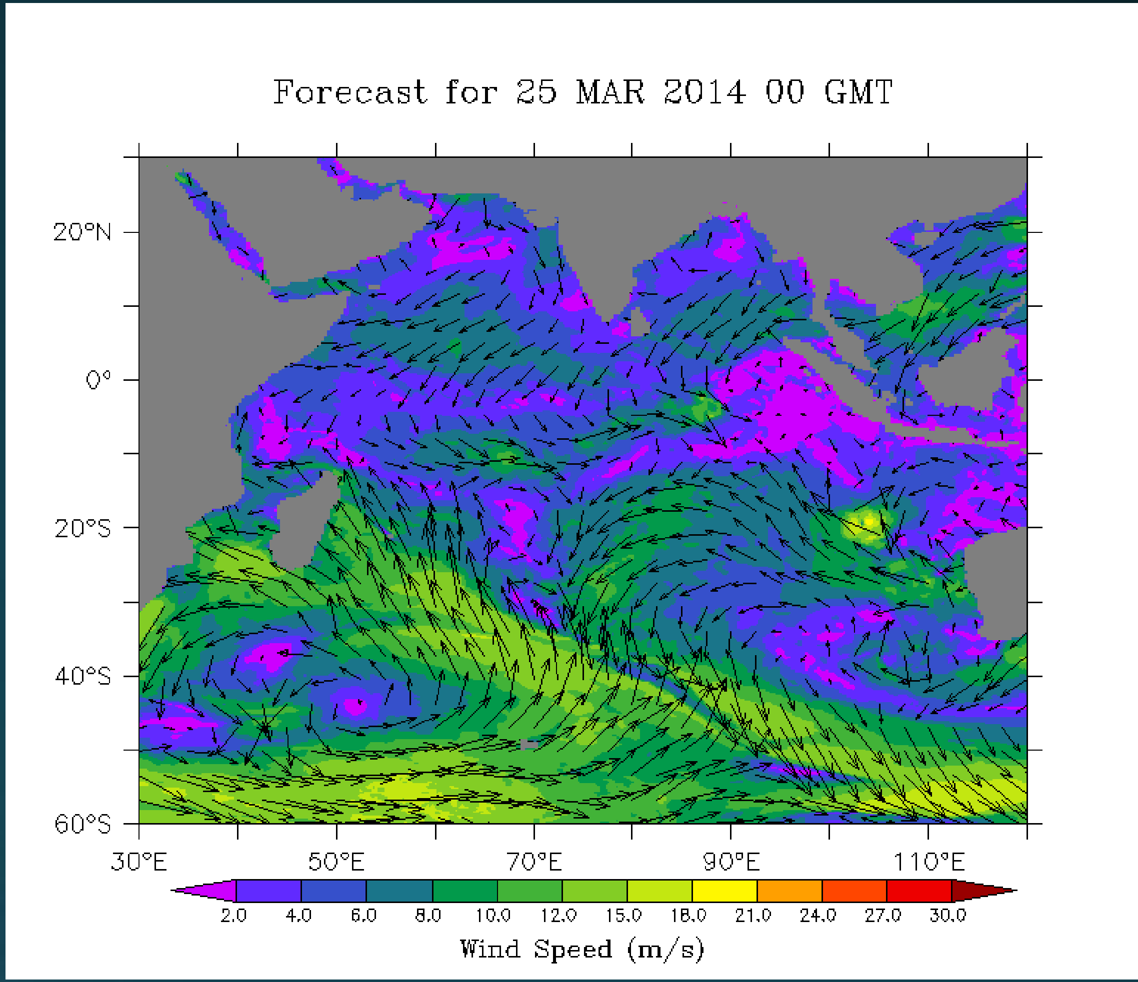
- Zero spectra
  - the wave action is set to zero in all grid points
- Spectra from empirical formulations
- Spectra from a file
  - This type can be used to hotstart from a previous simulation

How the wave model works ?

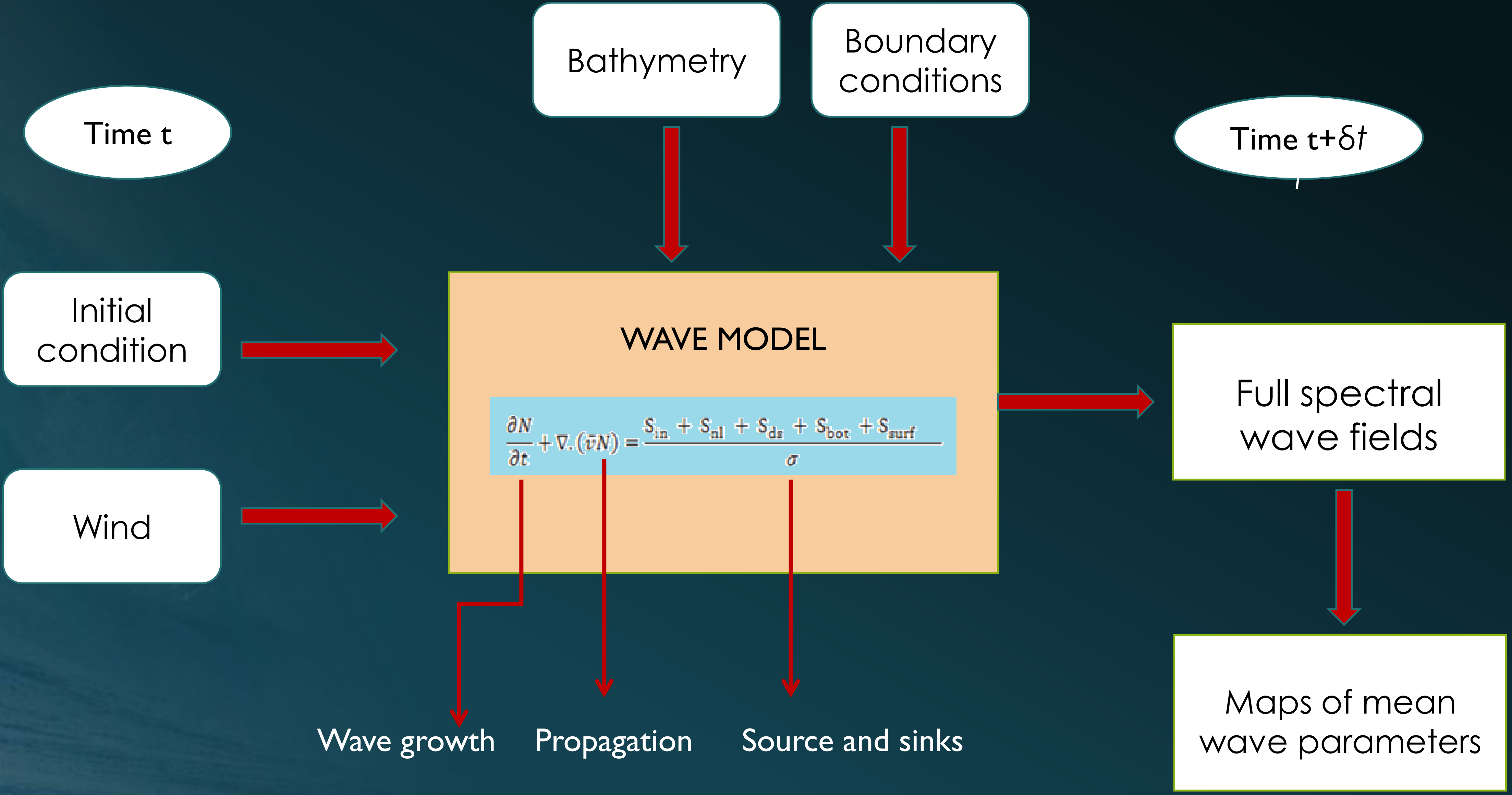


➢ Transfer of energy to the wave field is achieved through the surface stress applied by the wind

➢ Varies roughly as square of the wind speed

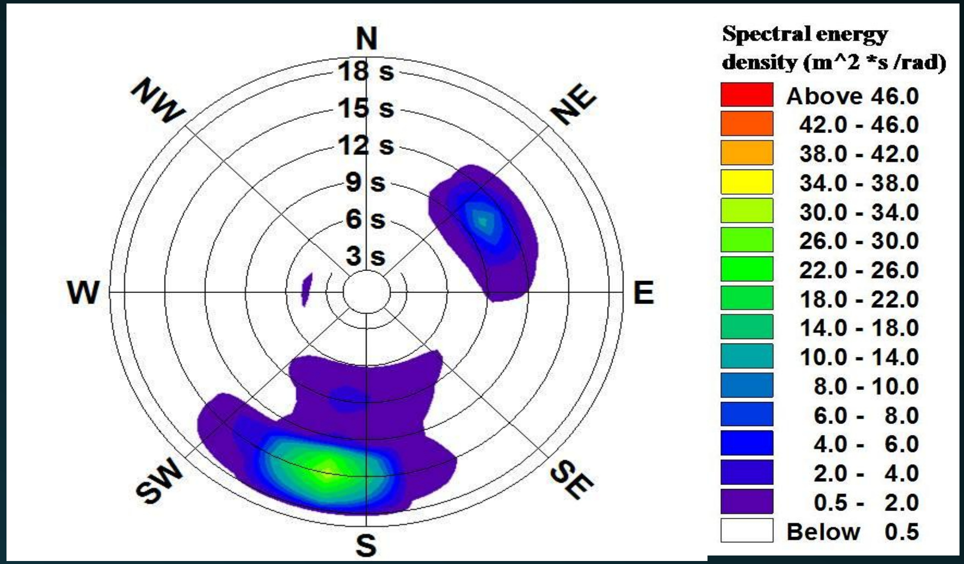


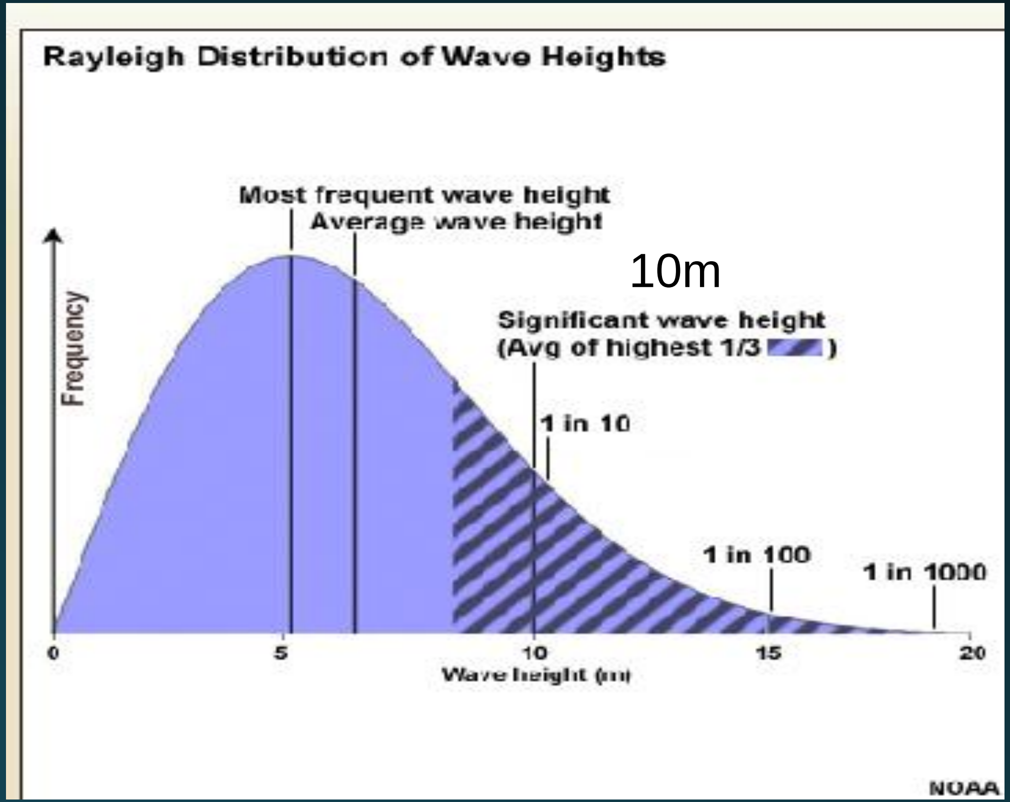
How the wave model works ?

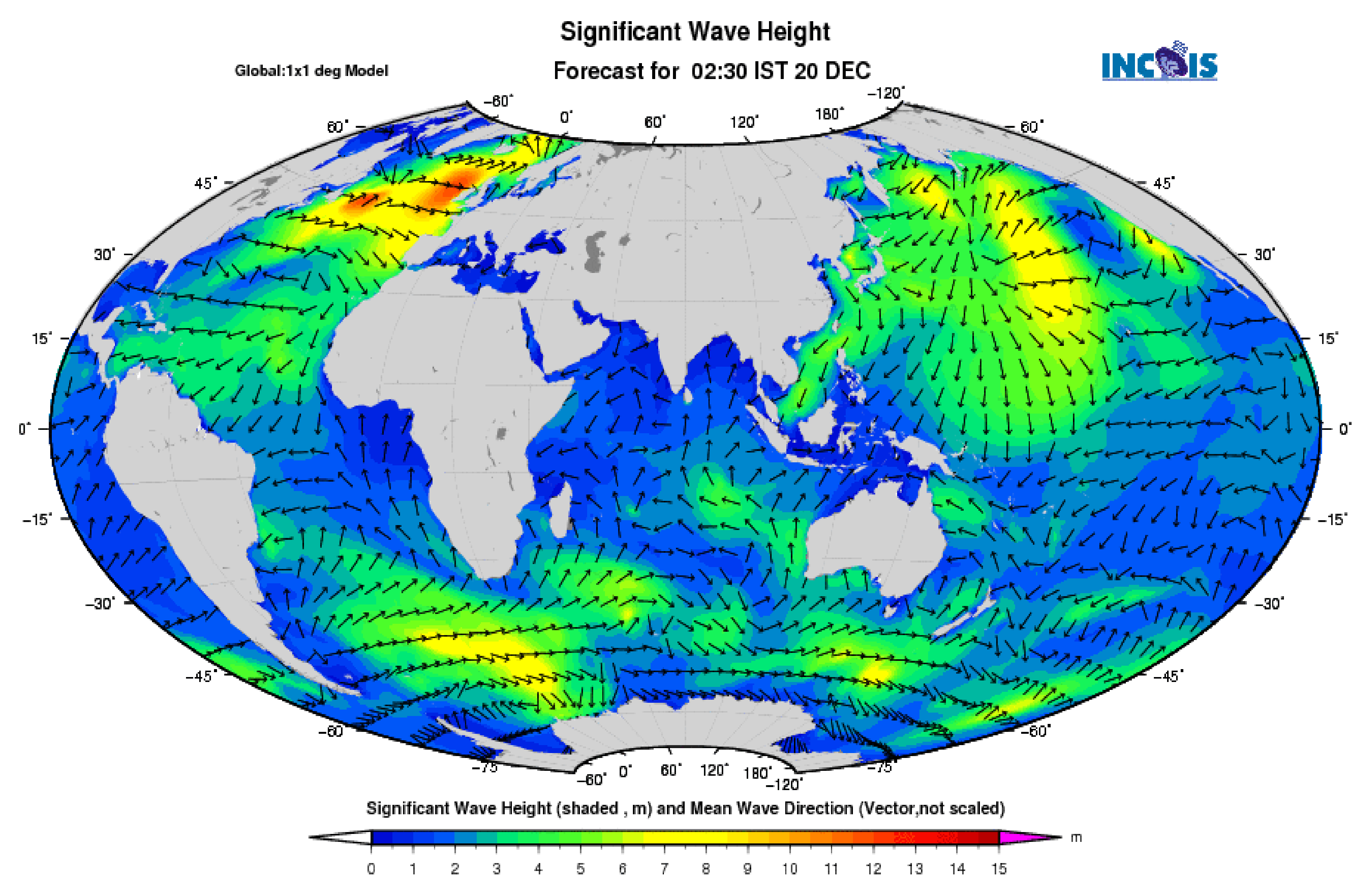


Spectral Information

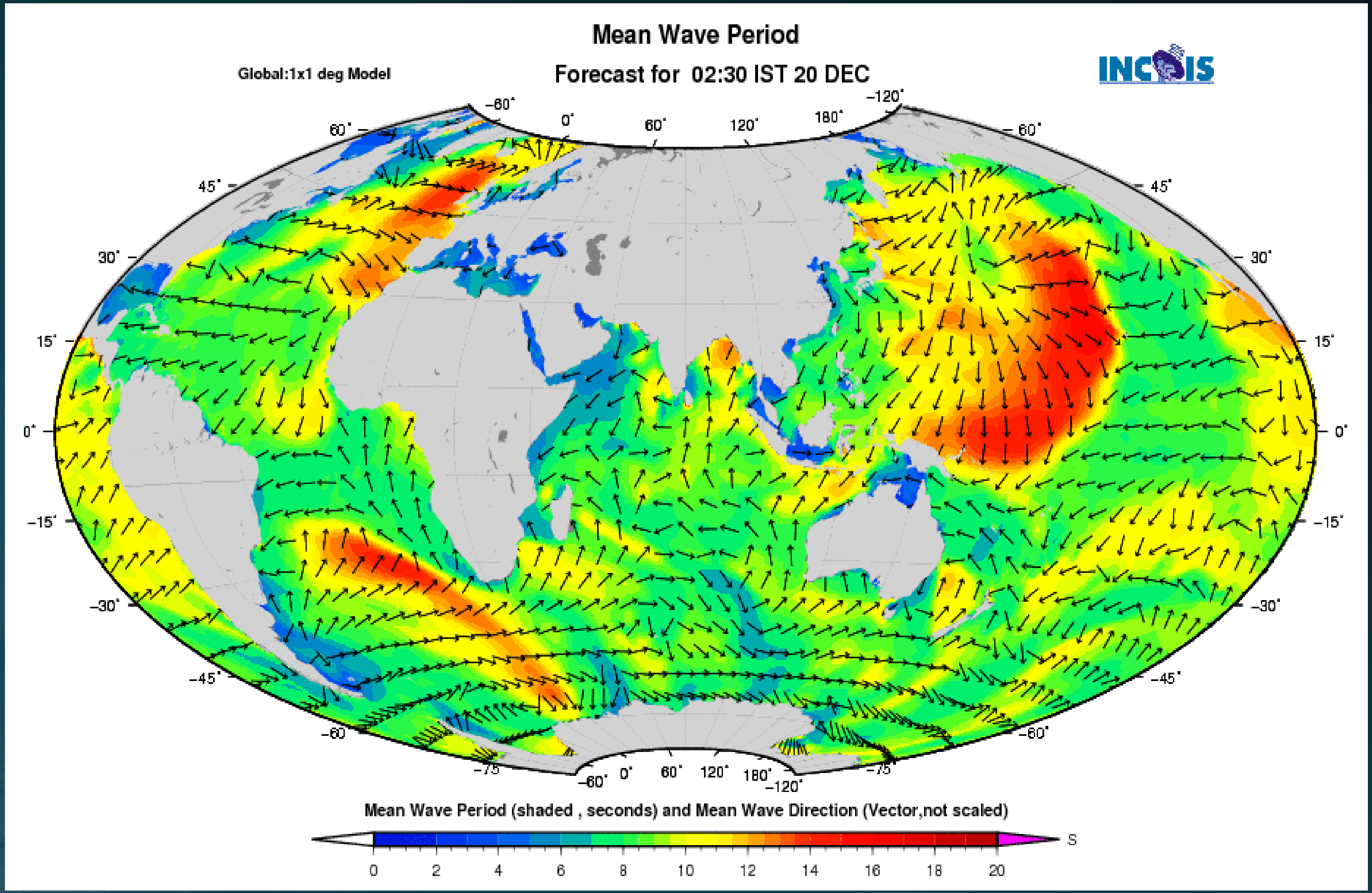
- Statistical averaging over spectrum
- Significant wave height



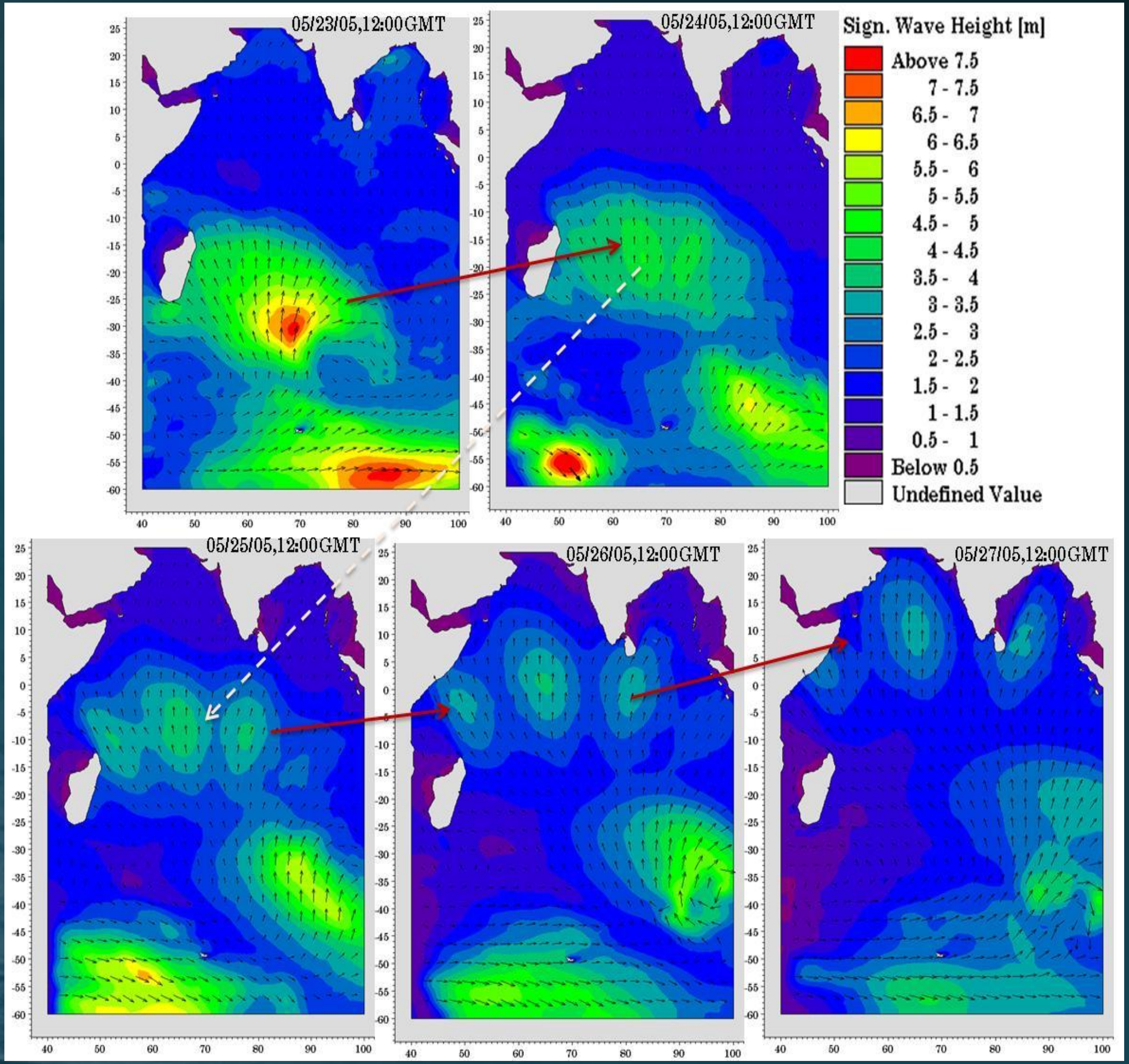


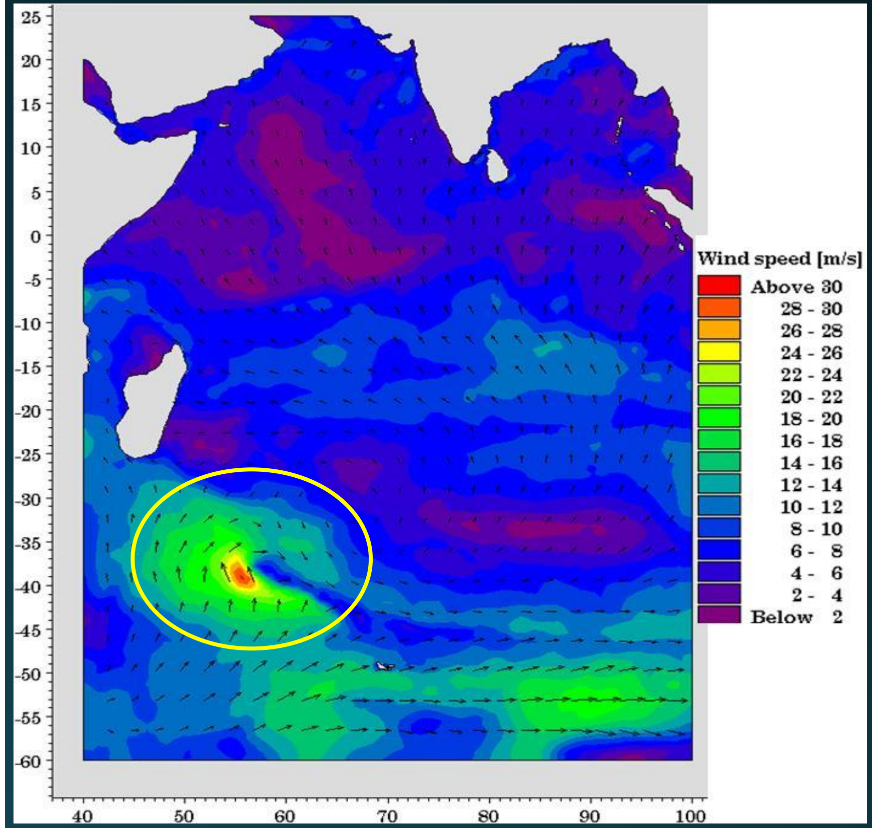


Significant Wave Height
Global:1x1 deg Model
Forecast for 02:30 IST 20 DEC
INCOIS
Significant Wave Height (shaded , m) and Mean Wave Direction (Vector,not scaled)
m
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15


Mean Wave Period
Global:1x1 deg Model
Forecast for 02:30 IST 20 DEC
INCOIS
Mean Wave Period (shaded , seconds) and Mean Wave Direction (Vector,not scaled)
0 2 4 6 8 10 12 14 16 18 20
S

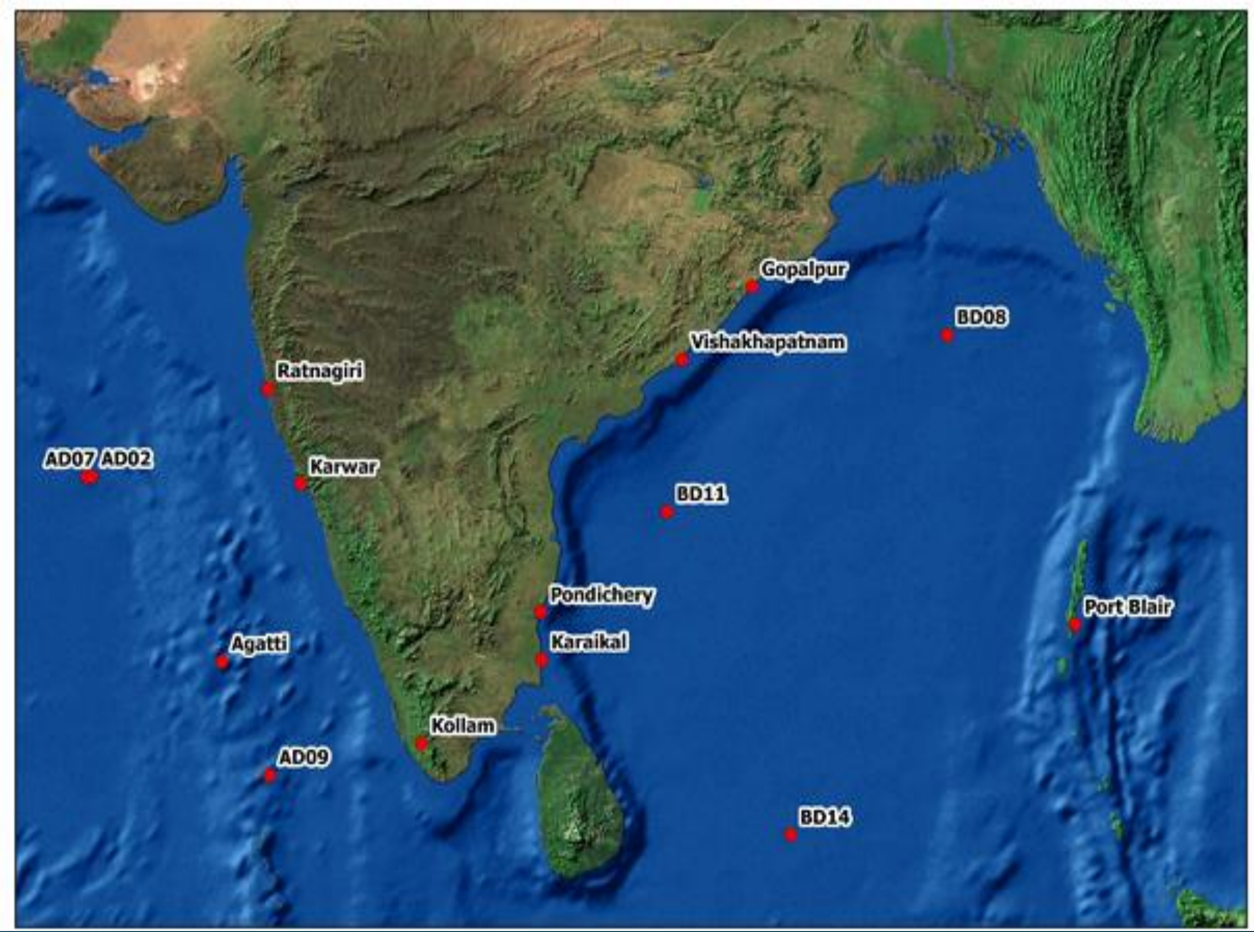
Southern Ocean swell wave propagation towards North Indian Ocean



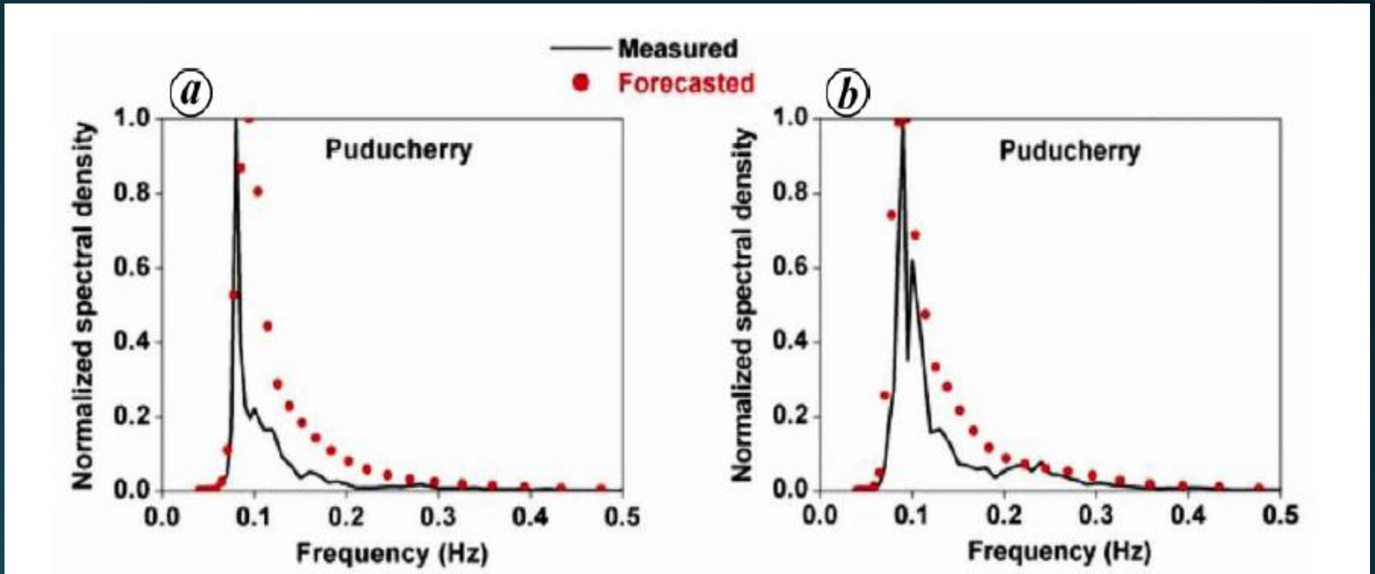


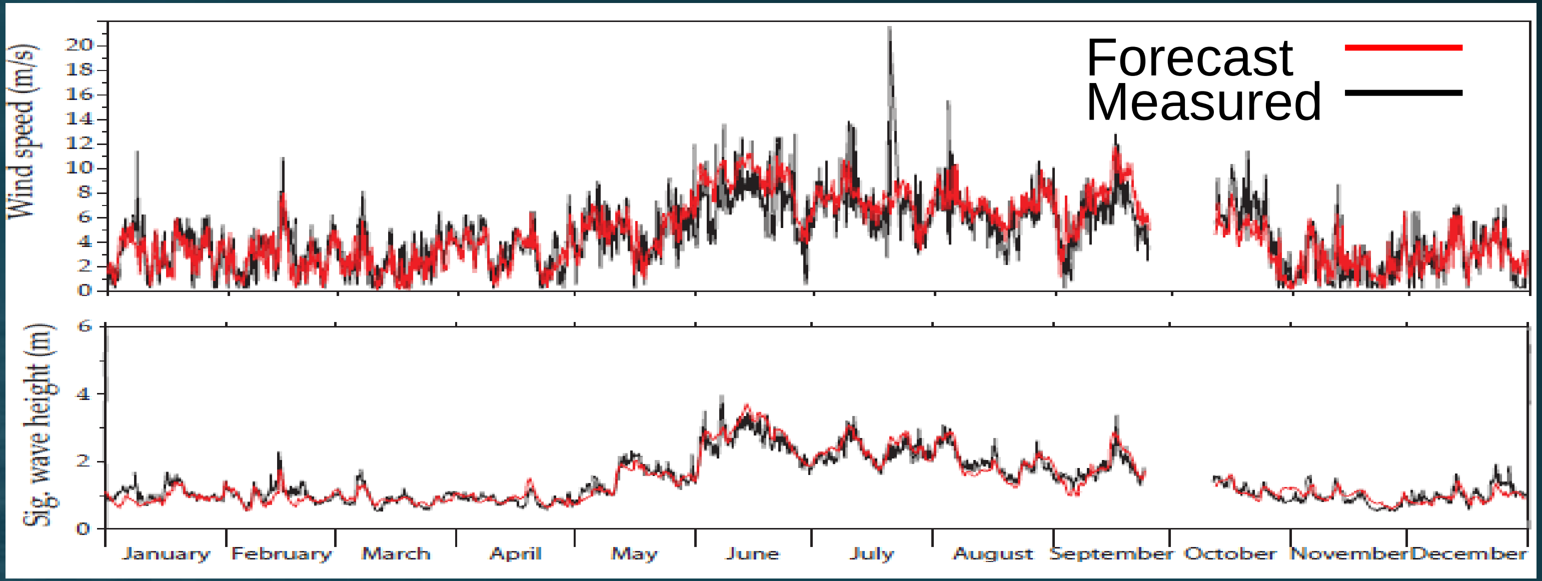
Southern ocean storm

Indian Ocean Buoy Network



Forecast validation using buoy measurements

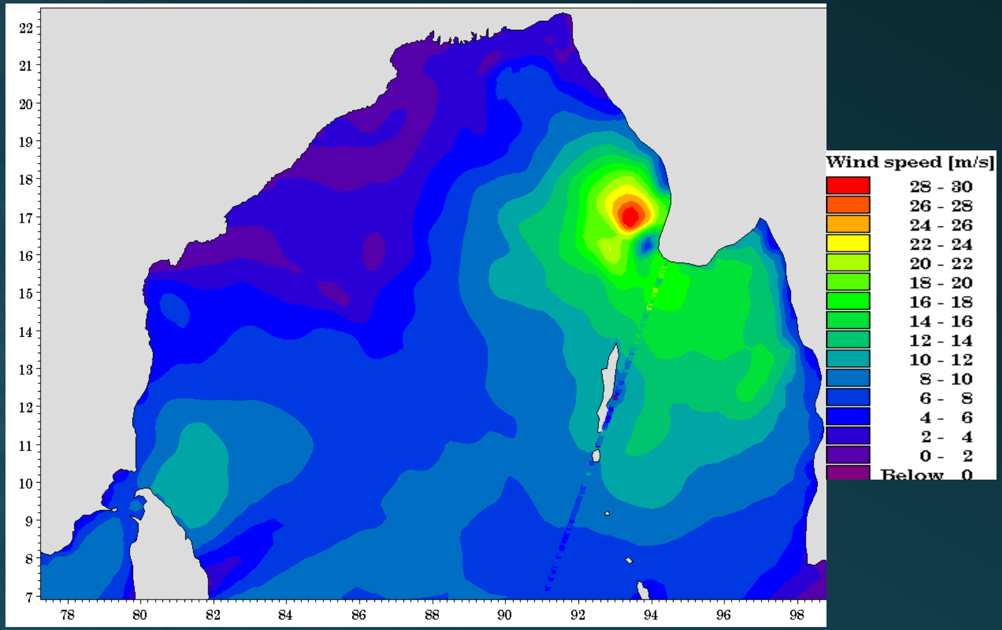


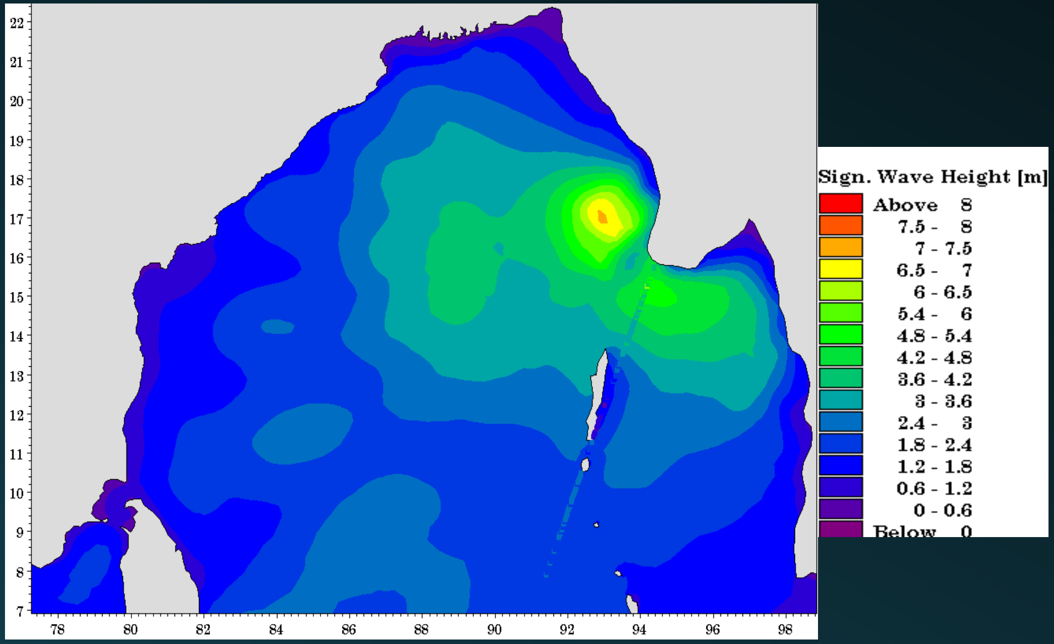


Model error statistics

	Parameter	Bias	RMSE	SI	R
Arabian Sea(49151)	ws (m/s)	0.28	1.37	0.21	0.89
	Hs (m)	0.15	0.35	0.18	0.96
BoB (24479)	ws (m/s)	0.28	1.59	0.26	0.83
	Hs (m)	0.25	0.44	0.22	0.9
South Indian Ocean (118996)	ws (m/s)	0.47	1.66	0.19	0.91
	Hs (m)	0.4	0.66	0.2	0.95

Synoptic map of model derived wind speed and wave height with Jason-1 Altimeter Track overlaid





Current satellite altimeters : Jason-2 , Saral, Cryosat-2

RADS(rads.tudelft.nl/)

Suggested Literature

Waves in oceanic and coastal waters ,Leo H. Holthuijsen,2007, Cambridge university press

Guide to analysis and forecasting,WMO-No.702,1998

Thank you for your kind attention !!!