Time stepping

Hendrik Tolman

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:

- Basic time steps per grid.
  - Time steps versus limiter.
- Mosaic model runs.
  - General grid interactions.
  - Overlapping grids.
- Impact of output.

There are four basic time steps per grid:

- Overall time step to propagate solution.
- Time step for lowest model frequency in absence of currents to assure stable propagation (CFL).
- Refraction time step.
- Minimum source term time step.

- This is the order in the input file,
- But CFL is most important, and therefore discussed first.

- Qualitative here only, practical examples are all over the test cases provided with the model.

CFL time step:

- Only explicit FD propagation schemes are available.
  - CFL criterion means that information can only be propagated by discrete number of grid boxes per time step.
    - Depends on propagation scheme.
    - All schemes available now allow one grid box.
  - Violate it and the model will blow up (eventually).

- In the code:
  - CFL time step adjusted as a function of frequency (longer time steps for higher frequencies).
  - CFL time step dynamically adjusted for current velocity:
    - Should stay stable, but
    - Strong currents may slow down model.

Overall time step:

- The model allows for larger overall time steps, to acknowledge that the lowest frequency rarely contains information.
- Accuracy requires relatively small factor between CFL time step and overall time step (say 2~3).
  - Do not want to propagation information over barely resolved bathymetry in overall time step.
- Ratio of overall / CFL time step directs needed overlap between equally ranked grids (more on day 2).

Refraction time step:

- "Refraction" includes great-circle direction change, depth and current refraction, and current induced wavenumber shifts.
- Refraction due to depth and current is filtered to assure stable solutions with large local depth changes.
  - Filter per frequency.
  - Fraction of CFL can be set by user.
- Reducing refraction time step will reduce use of filter.
  - May be useful for pre-implementation testing of models.

- Generally kept large, but best set at half the overall time step, to avoid numerical wiggles due to alternate orders of computation.

Minimum source term time step.

History:

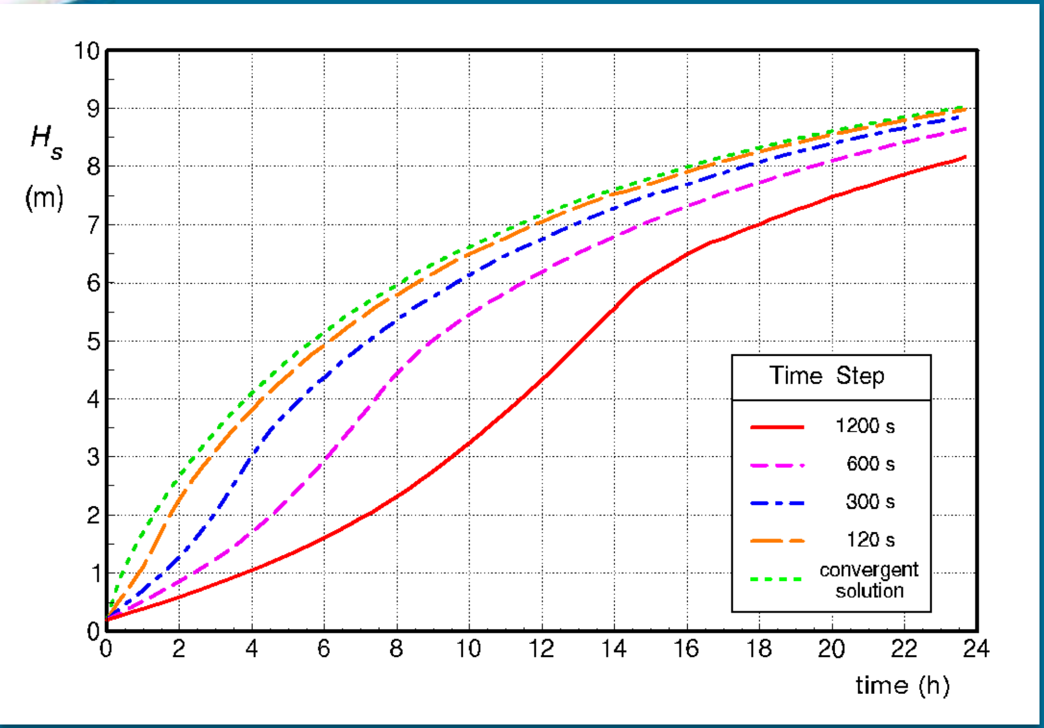
- WAM model used “limiter” to curtail the source term change of the spectrum per time step to assure integration stability for large source term time step.
- This has an impact on the solution, as will be shown below.
- WAM went to non-convergent limiter:
  - Minimal impact of time step on solution, but
  - Limiter becomes part of solution.
    - OK for engineering application.
    - Not good for research, since impact of limiter cannot be split from explicit physics.
- SWAN also uses limiters in iterations.

More history (details in manual):

- WAVEWATCH II (not III !):
  - Use limiter to dynamically adjust time step to get accurate yet economical source term integration.
    - Compare to parametric change.
    - Compare to (filtered) relative change.
    - Do not apply in tail.
    - Apply limiter if computed time step is less to allowed minimum time step.
  - Need to know something about limiters as they still are used depending on setup of model.
- Smaller minimum time step results in smoother model, often in faster model.
  - I generally use 5~60 s.

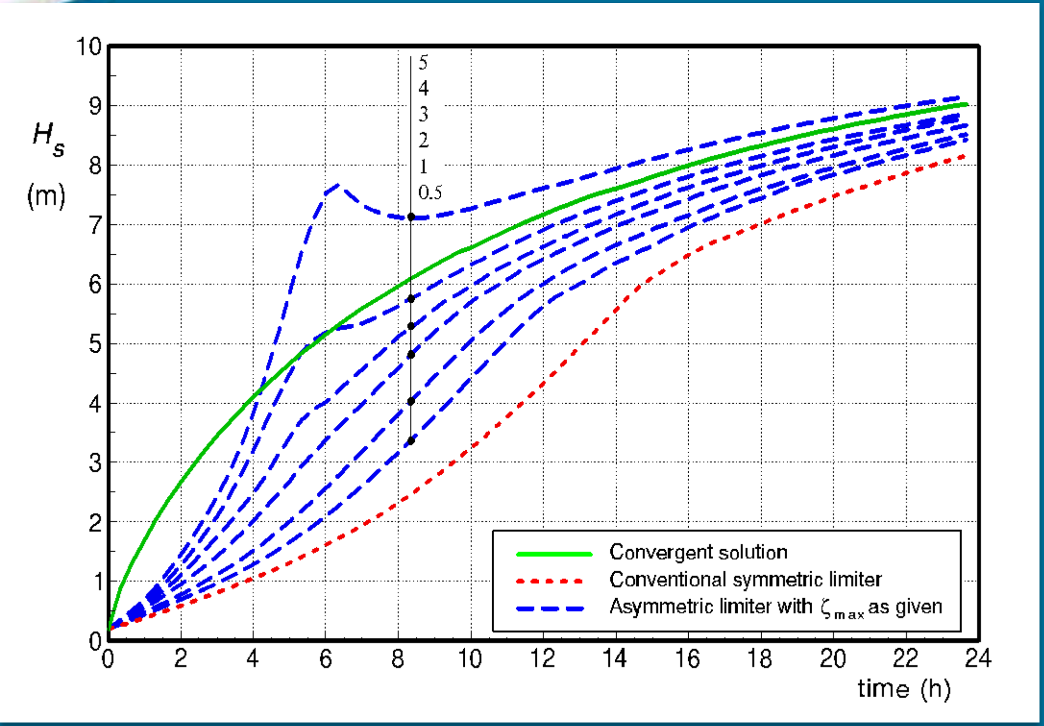
Tolman 1992: *JPO*., **22**, 1095-1111.
Tolman 2002: *GAOS*, **8**, 67-83.

Simple WAM-3 time limited growth test.



- Old convergent limiter.
- Initial growth strongly influenced even for small Δt.
- Convergent solution reproduced by dynamic time step.

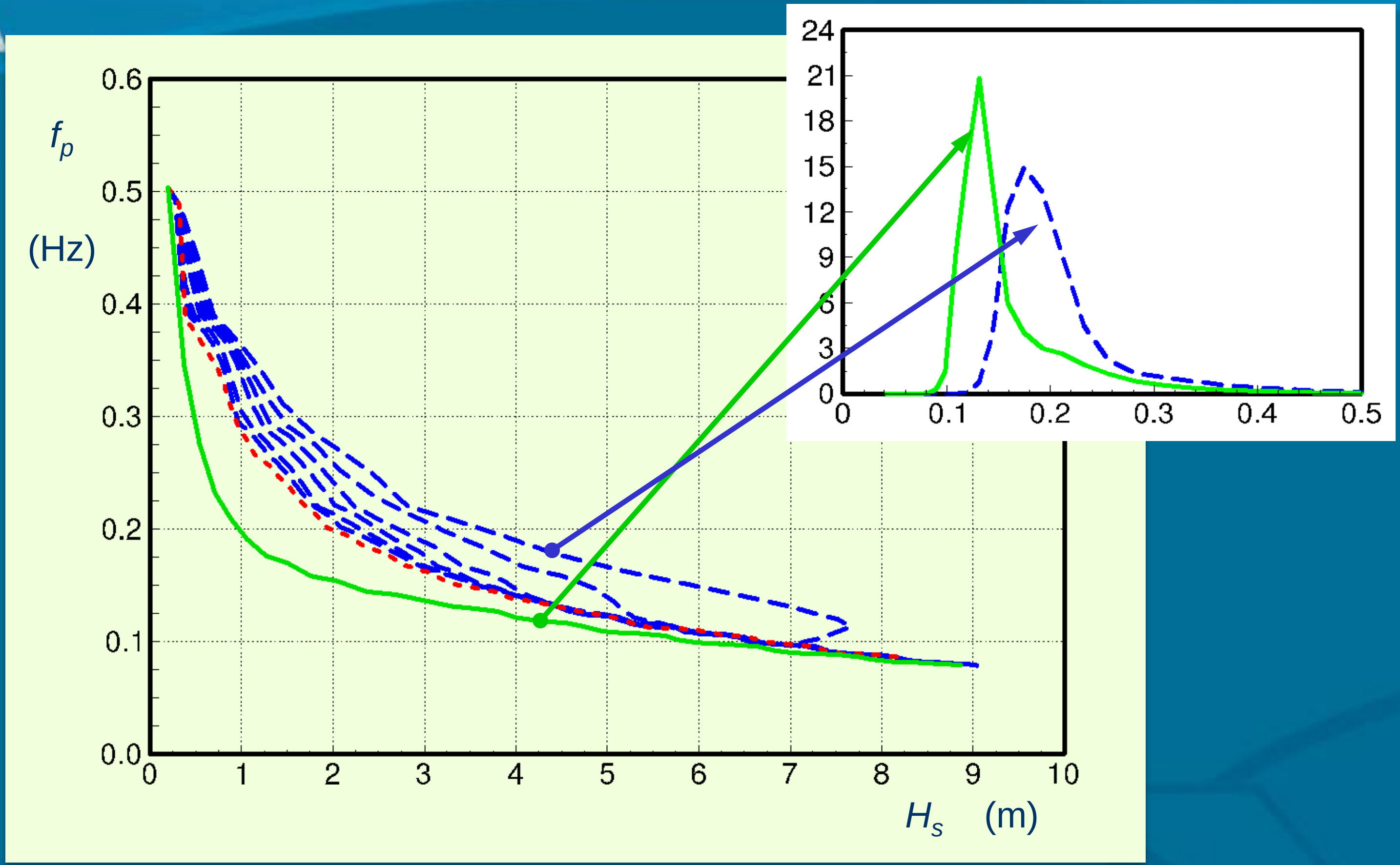
What about WAM-4 an SWAN approaches?
Good engineering, but good science?

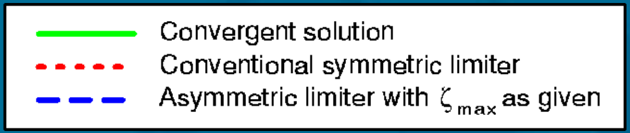


Asymmetric convergent limiter.

- All with Δt = 1200s
- Convergent, thus reduction in Δt get to true solution.
- Time step dep. remains for initial growth.

Feasibility study in Tolman (2002) only.
Might be useful for WAM or SWAN,



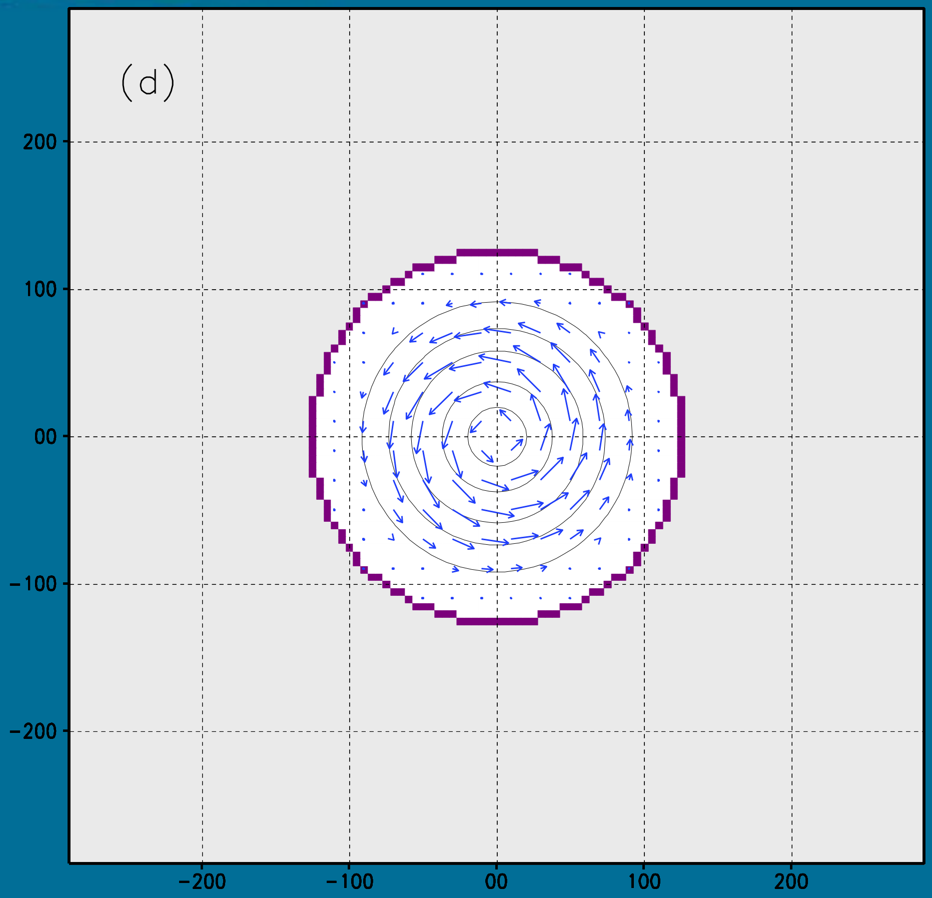


More accurate H_s with larger error in f_p.
I fear this is symptomatic for limiters.

Some multi-grid time step basics:

- In a multi-grid model the time stepping for grid is set up individually per grid.
- Two examples are given in the following slides.
  - Triple nest for swell propagation.
  - Triple nest for hurricane.
- You do not have to coordinate time steps per grid, but if you do not, you may have a problem predicting how this works.

Swell propagation



Boundary data grid with 1-D propagation.

Outer grid with full propagation but constant depth and no currents.

Inner grid with output locations.

Alternative inner grid with depth and current.

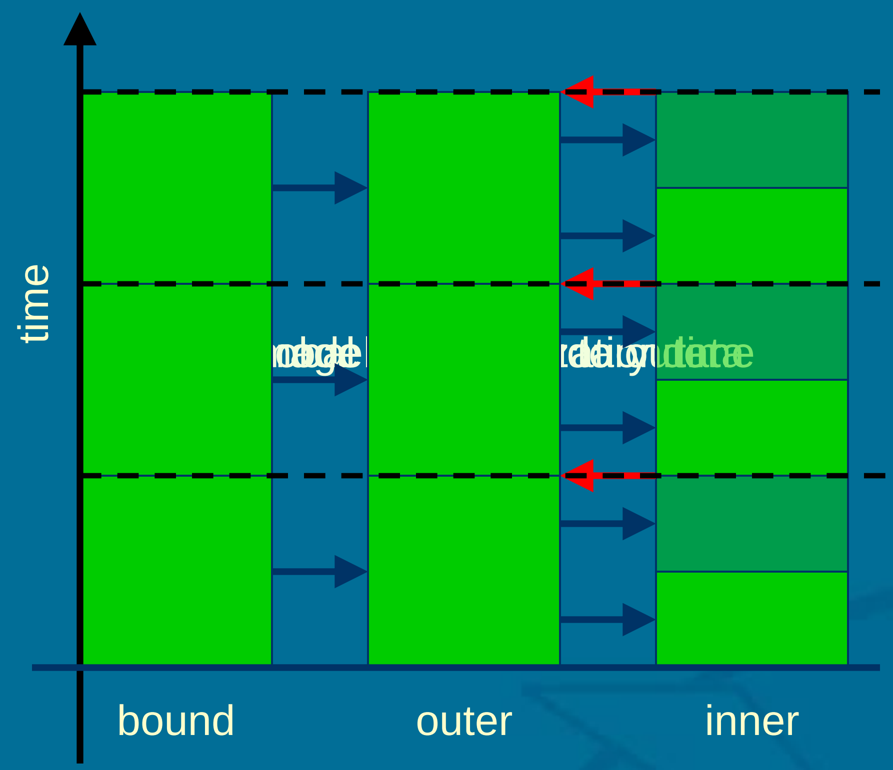
Swell propagation

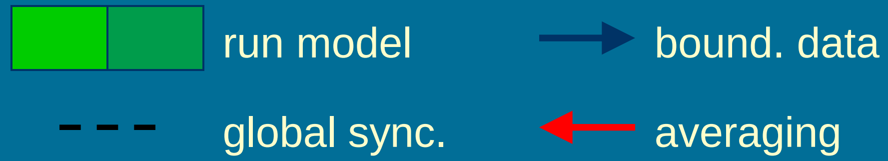
Boundary and outer grid share time step.

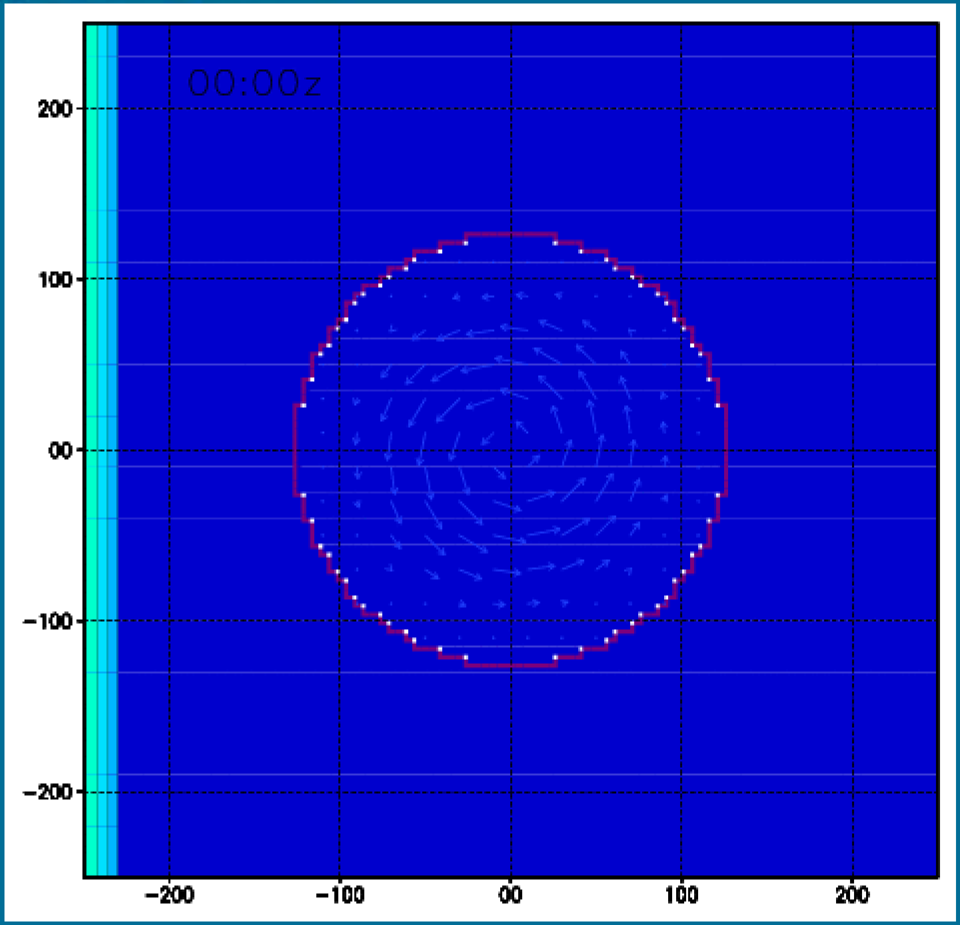
Boundary grid does not receive data back from outer grid.

Inner grid at half the time step of the outer grid.

Fully automated data flow / time stepping.





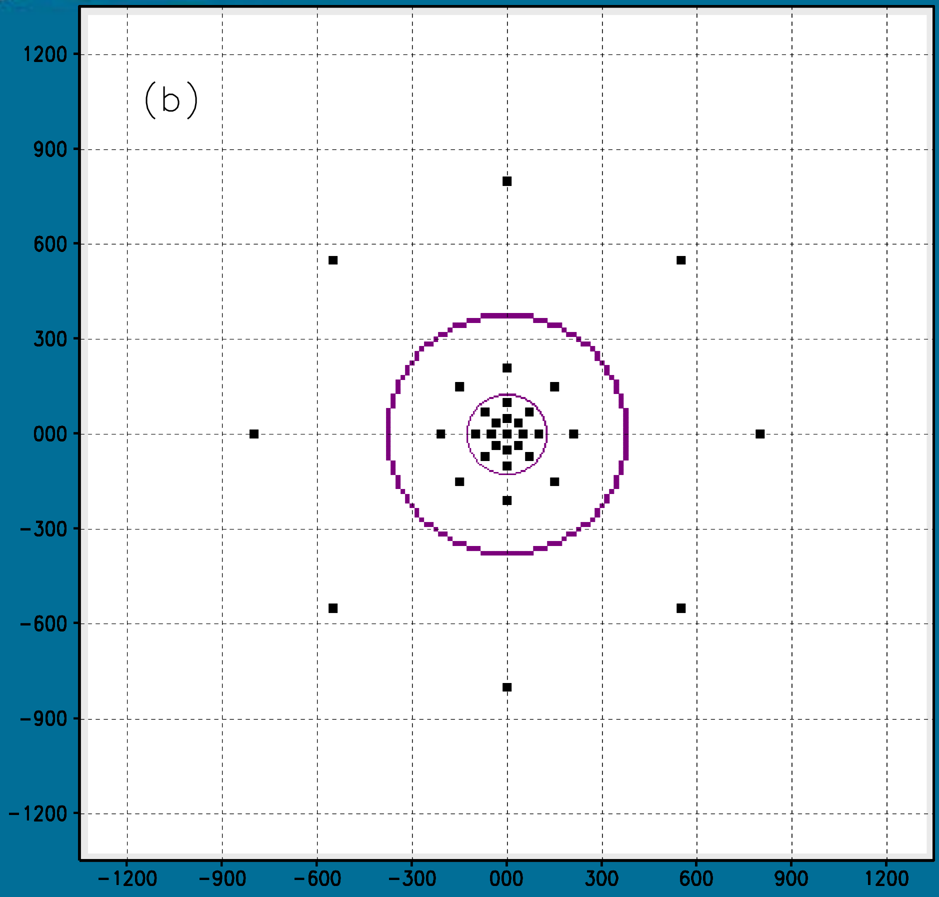


Current ring with circular inner domain. Input wave height is 2.50m, contours at 0.20m, including 2.40 and 2.60. Third order UQ scheme.

One-way nesting

Two-way nesting

Movie loop.



Hurricane described with Rankin vortex with maximum wind of 45 m/s at radius of 50km. Stationary hurricane or continuously moving grids.

Telescoping grids with 50, 15 and 5 km resolution.

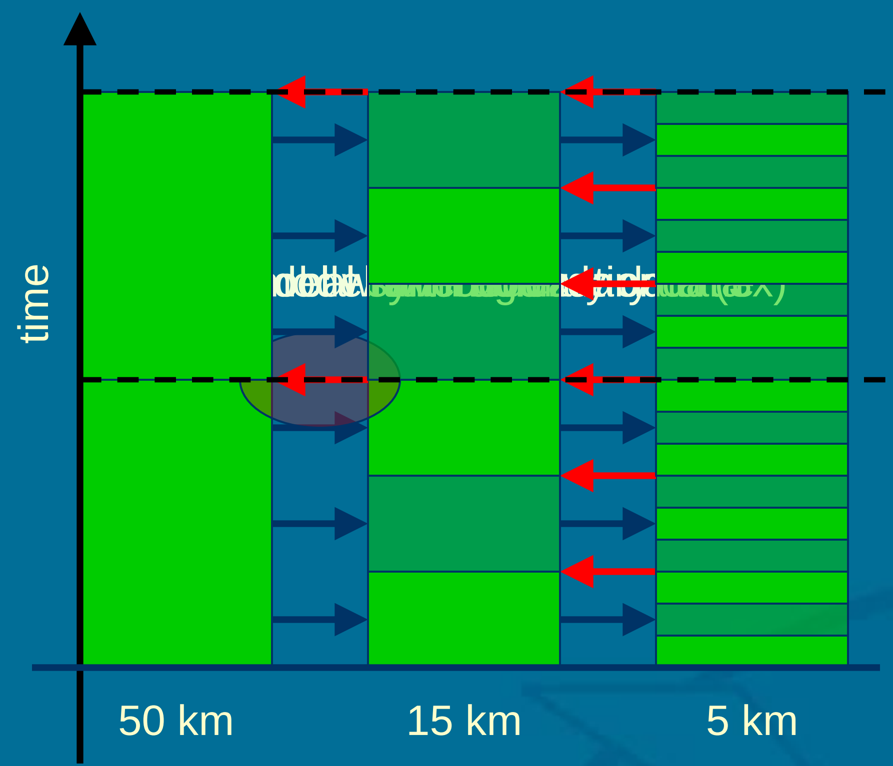
Alternative circular domains.

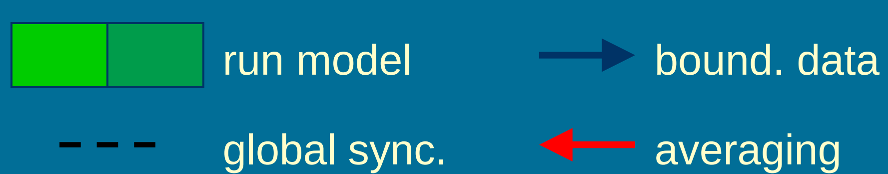
Hurricane

Factor 3 in time steps between grids.

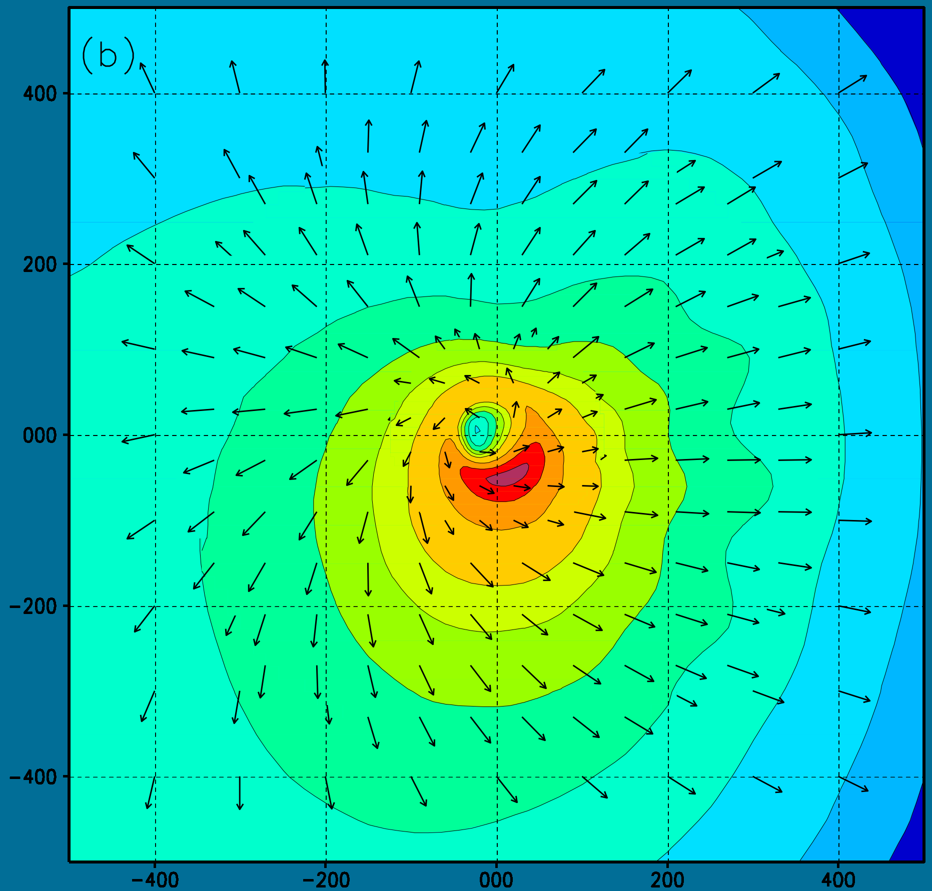
Full communication between grids

Fully automated data flow / time stepping.





Hurricane



Hurricane moving to the right at 5m/s with circular domains and Tolman and Alves (2005) moving grid approach.

composite of grids

multi-grid model

Tolman and Alves, 2005: *Ocean Modelling*, **9**, 305-323.

This was all about running the model, But if you want output too …..

- The model is always providing data at all times for which output is requested.
  - Overrides overall time step in *ww3_shel* as needed.
  - Ditto impact in *ww3_multi*.

Pitfall:

- In example input files a single restart file is asked for at a single time.
  - Interval is set at 1 second.
  - Some folks changed the interval without changing the increment ……

The end

End of lecture