WAVEWATCH III Developers Meeting

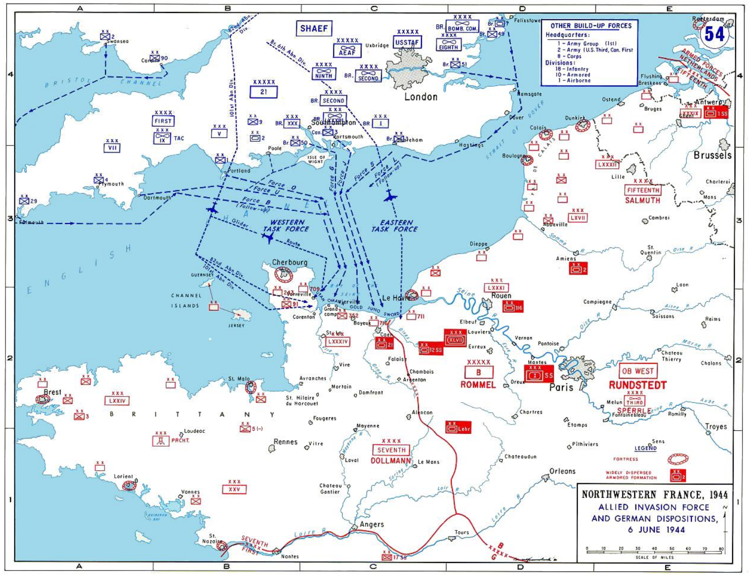
5 June 2019

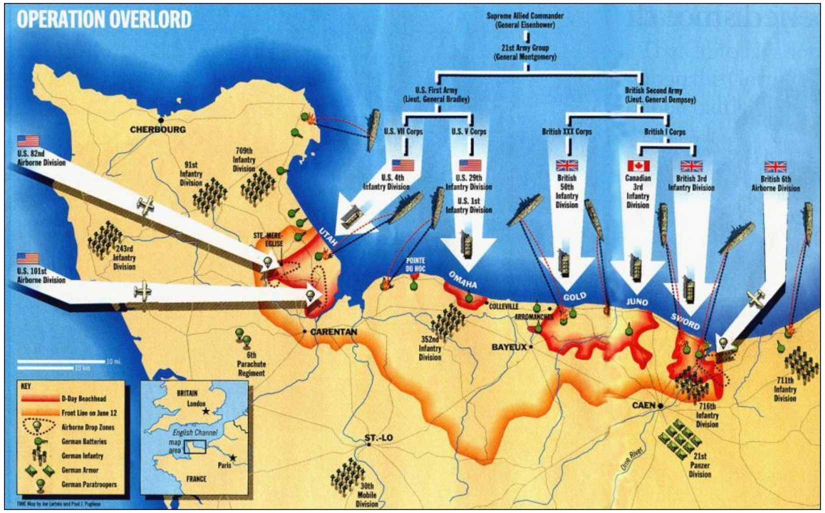
- Overview of WW3,
- GitFlow and GitHub repos,
- Repositories,
- Development workflow,
- Presentation Dr. Andrew Saulter (UKMO)
- Open Forum

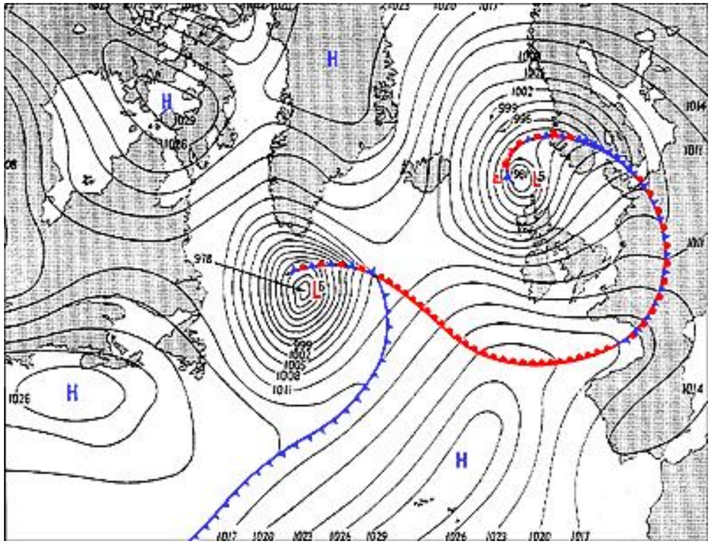
75 years of D-Day: Landmark for Wave Modeling

Sverdrup & Munk (1947)

- Approach predicted representative wave height for either windseas or swell:
- Military beach operations: Normandy,
- Advent of “wave modeling”







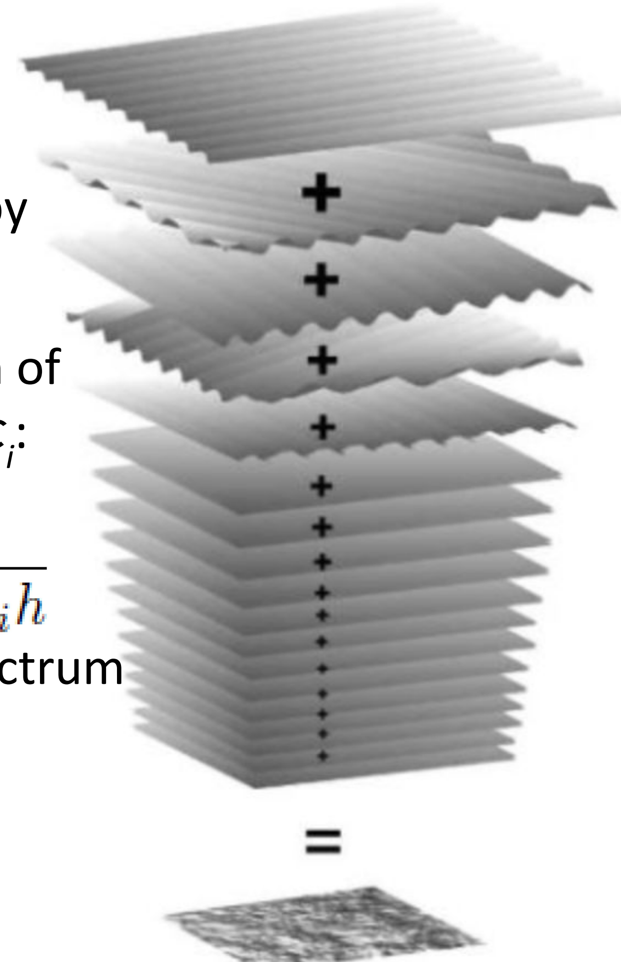
WAVEWATCH III is a Phase-Averaged (Spectral) Wave Model

- Computes changes of the wave spectrum over space and time
  - Requires two major solution steps
- Physics: Source Terms,

$$\frac{\partial N(\mathbf{i})}{\partial t} + \nabla_{\mathbf{x}} \bullet (\mathbf{c}_g + \mathbf{U}) N(\mathbf{i}) + \nabla_{\mathbf{i}} \bullet \mathbf{c}_{\mathbf{i}} N(\mathbf{i}) = \sum S(\mathbf{i})$$

- Numerics: propagation

Spectral representation of wind waves



Chaotic appearance of sea surface at generation zone represented by a Fourier model.

Thus the random ocean surface can be represented by

$$\eta(x,t) = \sum A_i sin(k_i x - \sigma_i t + \epsilon_i)$$

A wave energy spectrum can be defined as a function of the amplitude *A* of each spectral component $k_i x - \sigma_i t + \varepsilon_i$:

$$E(\omega, k, \theta) = \lim_{\Delta\omega \to 0} \lim_{\Delta k \to 0} \lim_{\Delta\theta \to 0} \frac{1}{\Delta\omega\, \Delta k\, \Delta\theta} E\{\tfrac{1}{2}\underline{a}^2\}$$

Since *f* and *k* are related through $\sigma_i = \sqrt{g k_i \tanh k_i h}$
we can fully represent sea state using a *f*,θ or *k*,θ spectrum

$$E(f, \theta) = \lim_{\Delta f \to 0} \lim_{\Delta\theta \to 0} \frac{1}{\Delta f\, \Delta\theta} E\left\{\tfrac{1}{2}\underline{a}^2\right\}$$

$$E(k, \theta) = \lim_{\Delta k \to 0} \lim_{\Delta\theta \to 0} \frac{1}{\Delta k\, \Delta\theta} E\{\tfrac{1}{2}\underline{a}^2\}$$

Fourier model assumes each spectral component is independent.
Measurements support idea as they propagate over long distances.

Source Terms in WAVEWATCH III

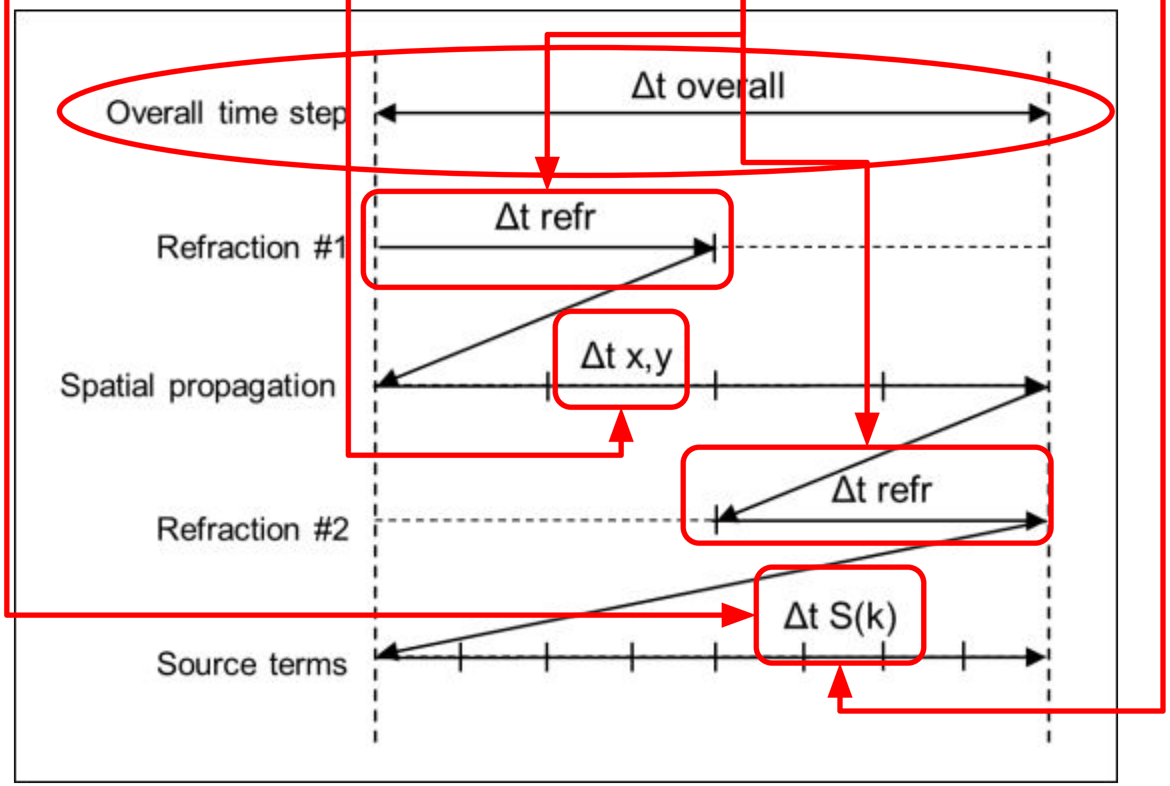
S_{nl}: Discrete Interaction Approximation (DIA)
S_{nl}: Full Boltzmann Integral (WRT) . . . . . .
S_{nl}: Generalized Multiple DIA (GMD) . . . . .
S_{nl}: Two-Scale Approximation (TSA) . . . . .
S_{nl}: Nonlinear Filter . . . .
$S_{in} + S_{ds}$: WAM cycle 3 . . . .
$S_{in} + S_{ds}$: Tolman and Chalikov 1996 . . . . .
$S_{in} + S_{ds}$: WAM cycle 4 (ECWAM) . . . . . .
$S_{in} + S_{ds}$: Ardhuin et al. 2010 . . . .
$S_{in} + S_{ds}$: Zieger et al. 2015 . . . .
S_{ln}: Cavaleri and Malanotte-Rizzoli 1981 . . .
S_{bot}: JONSWAP bottom friction . . . .
S_{bot}: SHOWEX bottom friction . . . .
S_{mud}: Dissipation by viscous mud (D&L) . . .
S_{mud}: Dissipation by viscous mud (Ng) . . . .
S_{db}: Battjes and Janssen 1978 . . . .
S_{tr}: Triad nonlinear interactions (LTA) . . . .
S_{bs}: Bottom scattering . . . .
S_{ice}: Damping by sea ice (simple) . . . .
S_{ice}: Damping by sea ice (generalization of Liu et al.)
S_{ice}: Damping by sea ice (Shen et al.) . . . .
S_{ice}: Frequency-dependent damping by sea ice . . . .
S_{is}: Diffusive scattering by sea ice (simple) . . . . .
S_{is}: Floe-size dependent scattering and dissipation .
S_{ref}: Energy reflection at shorelines and icebergs . .

The WAVEWATCH III® Development Group (WW3DG), 2016: User manual and system documentation of WAVEWATCH III® version 5.16. Tech. Note 329, NOAA/NWS/NCEP/MMAB, College Park, MD, USA, 326 pp.

Numerics, Fractional Time Steps

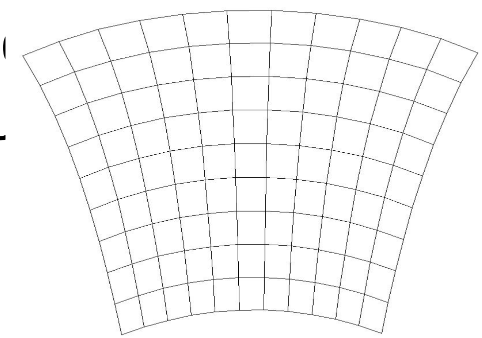
$$\frac{\partial N(\mathbf{i})}{\partial t} + \nabla_{\mathbf{x}} \bullet (\mathbf{c}_g + \mathbf{U}) N(\mathbf{i}) + \nabla_{\mathbf{i}} \bullet \mathbf{c}_{\mathbf{i}} N(\mathbf{i}) = \sum S(\mathbf{i})$$

Fractional step solution in WAVEWATCH III has four time steps per grid:

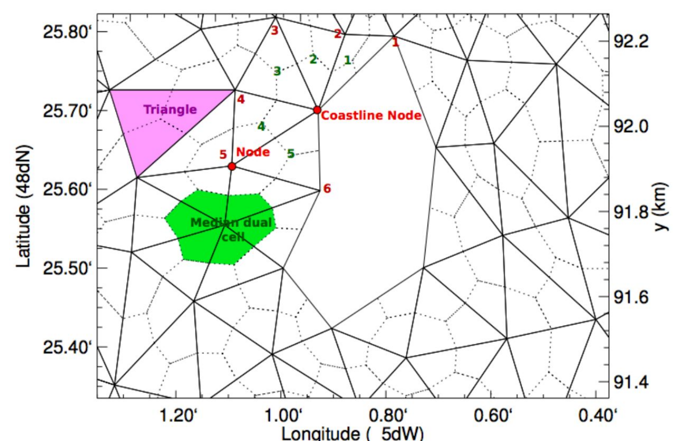


Numerics, Grid Types & Spatial Propagation

- Regular
  - Spherical or Cartesian, 3 options of propagation schemes:
    - 1st order,
    - 2nd order, Upstream Non-Oscillatory (UN
    - 3rd order, Quickest + Ultimate limiter + (U



- Curvilinear *(Lecture 5)*
  - Jacobian mapping onto straightened grid,
  - Same propagation schemes as regular,
  - Tripolar grid on WW3 version 5.16.
- Triangular unstructured *(Lecture 10)*
  - CRD-N (1O), CRD-PSI (2O space) CRDFCT (2O space-time),
  - Implicit N-scheme.
- Spherical Multi-Cell (SMC).



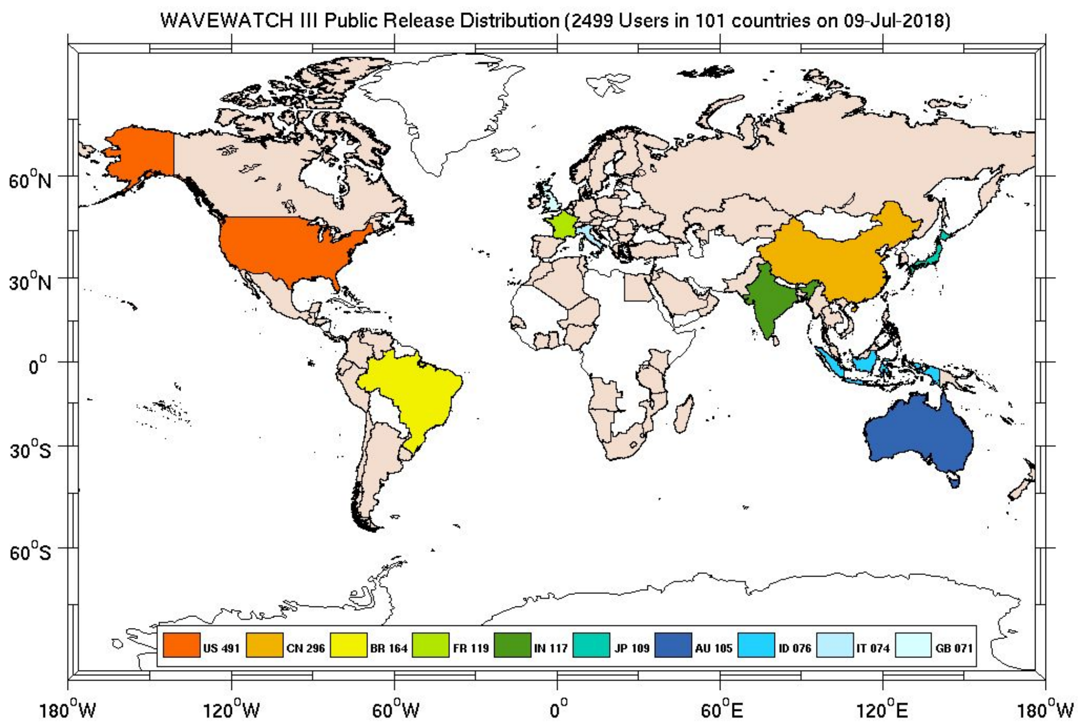
Numerics, Other Key Features

- Intra-spectral propagation,
  - Refraction and current-induced wavenumber shifts,
- Unresolved obstacles (islands etc),
  - Major source of local wave model errors,
  - Fluxes between cells are suppressed according to the degree of obstruction.
- Multiple grids, with two-way nesting,
- Continuously moving grids,
  - Waves in rapidly changing conditions, eg hurricanes,
- Rotated grids.

The WAVEWATCH III Model, Summary

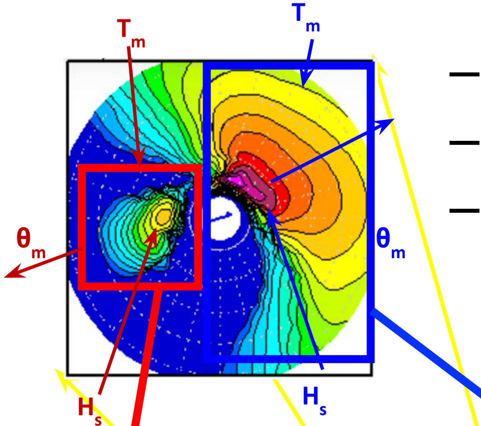
WAVEWATCH III is…

- State-of-the-art numerical model for wave prediction,
- Developed at NCEP in 90’s, became community model recently,
  - International development group
  - 2,499 users, 101 countries (07/2018).



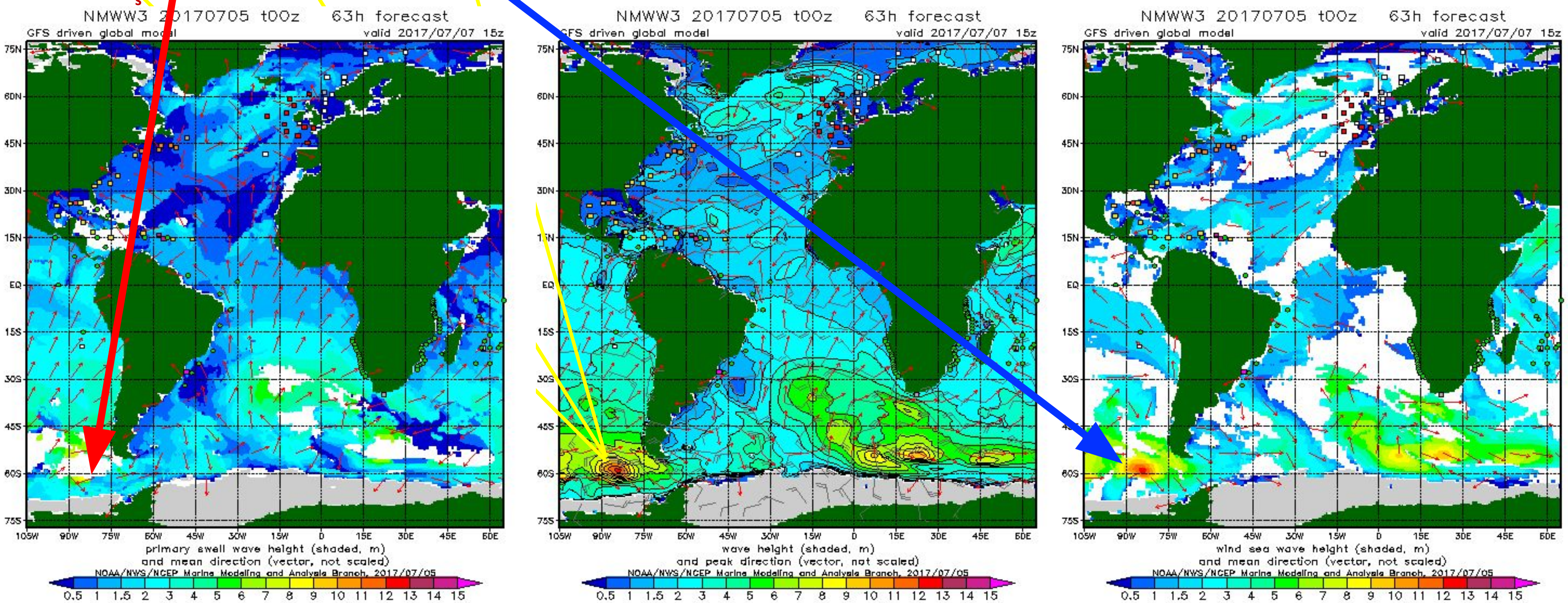
The WAVEWATCH III Model, Summary

- WAVEWATCH III in a nutshell,



  - Computes wave fields at grid points,
  - Changes to wave spectrum over space and time,
  - Provides mean wave parameters used in forecasts:
    - Significant wave height,
    - Peak and Mean wave periods (Tp, Tm),
    - Peak and mean wave directions (θp, θm),

$$H_s = 4\sqrt{\iint F(f,\theta)\,df\,d\theta}$$



Wave modeling at NCEP

- NCEP's first computer-aided wave forecast was made in 1956, producing only wave heights and period based on present and recent local winds (eg, MSB type model).
- In 1968, the system was expanded to estimate a single wind seas and a single swell (H_s, T_p).
- The first operational spectral wave was introduced at NCEP in 1985, and was based on Cardone's second generation SAIL model (first global, later regional).
- Some of these models were replaced by cycle 4 of the WAM model in 1994 and 1997.
- Development of an in-house third-generation model (WAVEWATCH III ®) started in 1993.
- From 1998-2000 all global-scale operational wave models at NCEP have become WAVEWATCH III based.
- Website with further information

WAVEWATCH III® development

WAVEWATCH III® public releases

- v 2.22
  - First official public release
  - single grid model
  - underpinning of the numerical scheme set
  - Modular Fortran 90 with MPI and OPENMP formulation
  - Tolman Chalikov physics and WAM cycle 3 physics
  - DIA and EXACT – NL
  - Regular grids (lat – lon spherical or rectilinear)
  - Finite difference in spatial and spectral domains
- v 3.14
  - Second release in 2007
  - Model expanded to two – way nested mosaic system with multiple grids
  - Linear growth term
  - Depth limited wave breaking
  - Numerical schemes for individual grids unchanged

WAVEWATCH III® development

WAVEWATCH III® public releases

- v 4.18
  - Third public release (March 19 2014),
  - Code development now by an international team of developers (svn)
  - Multiple grids formulation expanded to include curvilinear grids, unstructured grids and SMC grids
  - Ardhuin et al physics package,
  - Babanin et al physics package,
  - Second order spatial propagation scheme,
  - Iceberg blocking ,
  - Multiple wave – mud and wave – ice interaction packages,
  - Netcdf I/O added,
  - Triads interactions,
  - Expanded field of outputs (primarily for coupling),
  - SHOWEX bottom friction source term,
  - Grid splitting auxiliary code (for hyper scaling).

WAVEWATCH III® development

WAVEWATCH III® public releases

- V 5.16
  - Fourth public release (October 31, 2016),
  - Sea-ice scattering and creep dissipation added Optimization and updates to IC3 and IC2,
  - Capability to handle cpp macros,
  - Updates to SMC grid time, OpenMP and hybrid OpenMP/MPI ,
  - Tripole grid functionality,
  - Updates/optimization to various source terms (IC2, IC3, ST4, ST6),
  - Coupler capabilities for NCEP coupler and OASIS coupler,
  - Namelist format option for multi grid input file (ww3_multi.nml),
  - Sea-state dependent stress calculations,
  - TSA nonlinear wave-wave interaction,
  - Calculation of space-time extremes.

WAVEWATCH III® development

WAVEWATCH III® public releases

- V 6.07
  - Fifth public release (April 2019)
  - Enhanced Stokes drift computation options,
  - New module for ESMF interface
  - Capability to update restart file's total energy based on independent significant wave height analysis,
  - Domain decomposition for unstructured implicit schemes using PDLIB,
  - Updates the namelist options for the following programs: ww3 ounf, ww3 ounp, ww3 trnc, ww3 bounc, and ww3 shel
  - Adding IC5 as a sea ice source term option,
  - Other additions include updates on source term parameterizations such IC2, IS2, ST4, REF1
  - Optional instrumentation to code for profiling of memory use,

WAVEWATCH III® development

WAVEWATCH III® current development

- V 7.01
    - Transition to open development using GitHub
    - Option for fixed-filename output in ww3_ounf
    - Generalization of comp/link scriptsGeneralization of comp/link scripts
    - Checkpointing
    - Memory localization
    - Wave partition data assimilation
    - MPI post processing
    - Complete namelist feature in all codes

WAVEWATCH III GitHub Repo

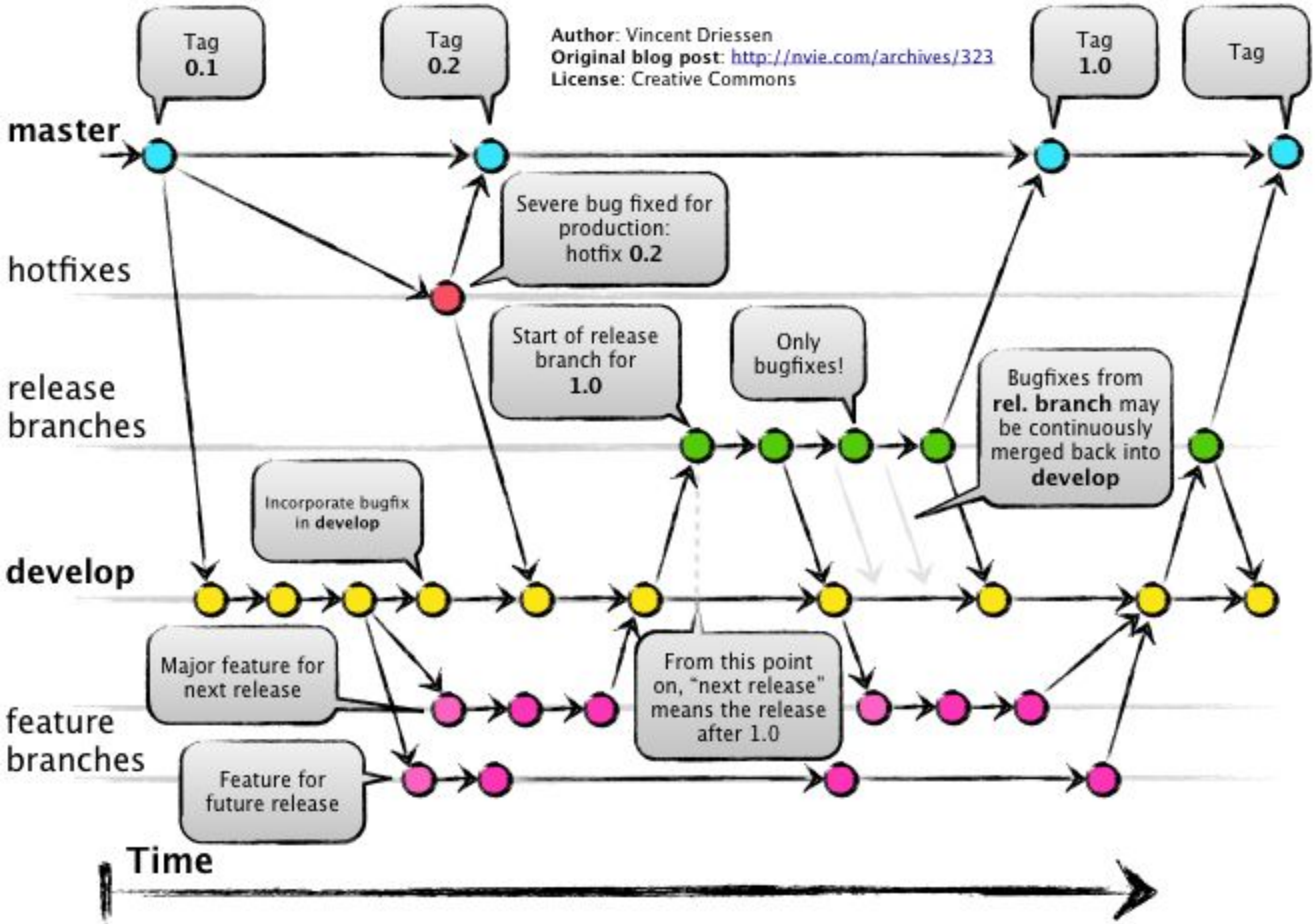
On April 2019 WAVEWATCH III entered open development

- Published GitHub repository
- https://github.com/NOAA-EMC/WW3

Development paradigm established using GitFlow conceptual framework:

- https://github.com/NOAA-EMC/WW3/wiki/WW3-Gitflow

The GitFlow Model



Vincent Driessen in 2010

WAVEWATCH III GitFlow for Developers

Developer Guide at GitHub wiki

- https://github.com/NOAA-EMC/WW3/wiki/Developer-Guide

GitFlow Rationale

- Two main branches
  - Master: public releases
  - Develop: all new ongoing developments
- Two types of repositories (source/destination of all codes)
  - Authoritative repository: NOAA-EMC (home of the master and public releases)
  - Trusted institutional repositories
    - Alongside auth repo, source for development work

Repositories

- Authoritative repository: NOAA-EMC/WW3
  - Code Managers: Jose-Henrique Alves and Ali Abdolali
- Trusted institutional repositories:
  - Ifremer (UMR-LOPS)
    - Code Manager: Mickael Accensi
  - ERDC/USACE
    - Code Manager: Tyler Hesser
  - UK MetOffice
    - Code Manager: Chris Bunney

All development will be made by forks out of one of these trusted institutional repositories, uder the develop branch.

Development workflow

“fork and branch" workflow

1. Fork the WW3 GitHub repository.
2. Clone the forked repository to your local system.
3. Add a Git remote for the original repository.
4. Communicate with the source repository code manager to indicate what is being developed
    a. Issues portal NOAA-EMC/WW3
5. Create a feature branch, make changes, commit and push changes to your GitHub fork.
6. Test your code for changes (see regression tests)
7. Open a pull request from the new branch to the original repo.
8. Clean up after your pull request is merged.

Questions?